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LECTURES

ON

NATURAL AND EXPERIMENTAL

PHILOSOPHY,

CONSIDERED IN ITS PRESENT STATE OF IMPROVEMENT.

DESCRIBING IN A FAMILIAR AND EASY MANNER

THE PRINCIPAL PHENOMENA OF NATURE;

AND SHEWING

THAT THEY ALL CO-OPERATE IN DISPLAYING THE GOODNESS, WISDOM, AND POWER OF GOD.

BY THE LATE

GEORGE ADAMS,

MATHEMATICAL INSTRUMENT MAKER TO HIS MAJESTY, &c.

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BY THE EDITOR.

LECTURES

ON

NATURAL PHILOSOPHY.

OF THE

NATURE AND PROPERTIES

OF

WATER.

LECTURE XIII.

THE study of nature is as much distinguished from other subjects by the importance of its matter, as by the variety of its topics. But amidst all this variety, the true philosopher is interested by the objects, only in proportion to the indication they afford of design and providence in the government of the world. This consoling testimony you will find spread abundantly over the face of nature; it is every where distributed into masses and portions, according to the nature of the subject. Every object we meet with, great or small, bears the stamp of an All-perfect Creator, is a mark of his wisdom, a monument of his power, and a proof of his goodness: many instances of the order, beauty, harmony, and proportion, in the works of nature, have been exhibited in the foregoing Lectures. The subjects that I am

about to treat of in this Lecture will furnish us with more. As you advance in the knowledge of nature's varieties, your mind will be opened, and you will find fresh ornament in truth, fresh dignity in devotion, and fresh reason in religion.

From treating of air and fire, I now proceed to consider the nature of water, whose wonderful properties are alone an abundant source of knowledge. It is a substance that in a certain degree of heat is fluid, in a less it is solid, and with a greater degree is convertible into an elastic vapour of incredible force. It is capable of dissolving all kinds of salts, of absorbing and detaining in its substance the air of the atmosphere, of being elevated and suspended in immense quantities in the regions thereof. In the general economy of nature, water promotes solution, separation, association, and subsidence. It is a substance which enters into so many operations both of nature and art, that to give you a full description of its properties would include those of most other substances.

Its weight is used as the measure of specific gravity.* Its temperature at the changes from solidity to fluidity, and from thence to the elastic state, are taken for the fixed points of thermometers.

Water constitutes not only the principal part of blood, milk, wine, oil, and other fluids, but also enters in a large proportion into the constitution of the solid parts of all animal, vegetable, and of many mineral substances.

Water serves to the art and navigation of man, as air serves to the wings of the feathered species. It is the easy and speedy medium, the ready conduct and conveyance, whereby all redundancies are carried off, and all wants supplied. It makes man as it were a denizen of every country on the globe. It

* A cubic foot weighing 1000 ounces avoirdupois. EDIT.

shortens every distance, and ties the remotest regions together. It carries and communicates the knowledge, the virtues, the manufactures and arts of each clime to all. It gives springs to industry, energy to invention.

OF THE COMPOSITION AND DECOMPOSITION OF WATER.*

Until very lately this fluid has been always considered as a simple substance. The experiments of M. *Lavoisier*, which I have related to you in a former Lecture, has induced many to consider it as a compound, consisting of inflammable and vital airs: in other words, that the whole mass of any quantity of water may be converted into inflammable and vital air: and that the combustion of these airs produces a volume of water proportioned to the weight of the airs employed in the experiment. Though I have already shewn you, that the experiments of M. *Lavoisier* and the French chemists by no means warrant the deductions they have made from them, yet as they have made these experiments the basis of a new system of chemistry, and have invented and appropriated a new set of terms in order to propagate it more readily, it will be necessary in this place further to investigate the subject.

That their experiments do not authorize their conclusion, appears from this, that when vital and inflammable airs are decomposed by heat, we find, both from the experiments of Dr. *Priestley* and the French chemists, that the nitrous acid is always formed; and that though this acid has been said to come from the phlogisticated air, which could not be wholly excluded in the process, there are several

* Dr. *Priestley*'s Observations and Experiments on Air. *Keir*'s Chemical Dictionary.

considerations that prove the acid could not have this source; the more so, as this process does not at all decompose, or in the smallest degree affect phlogisticated air.

In whatever manner, says Dr. *Priestley*, vital and inflammable air be made to unite, some acid is produced, and in no case pure water. If iron, containing phlogiston, be heated in vital air; or if precipitate *per se*, containing vital air, be heated in inflammable air, fixed air is always formed; whereas, according to the modern hypothesis, water ought only to be produced in both cases.

Water, they assert, is always decomposed when it is made to pass over red-hot iron; the iron, according to their opinion, imbibing the acidifying principle, the remainder goes off in inflammable air. Now it is unfortunate for this hypothesis, that no substances will answer for this experiment, except such as have always been considered as containing phlogiston. It is therefore most probable to suppose, that the inflammable air is formed by the phlogiston from these substances, water being the base; and that if any part of the substance remain and acquire weight, it receives that additional weight from water only.

That phlogiston is an element of water seems probable, 1st, because water conducts electricity like metals and charcoal, into which the same principle enters; and, 2dly, because when fresh distilled, it attracts vital air from the atmosphere, which is also a property of other bodies containing phlogiston. In this sense it may be said to contain both the principles of the new theory, though it is a sense that entirely overthrows that theory.

Without however entering more minutely into this investigation, it is sufficient to observe, that the formation of nitrous acid from the combustion of inflammable and vital airs, clearly proves, that water

is not a compound of these airs; or that it is only so, in a certain proportion of these ingredients, while another proportion yields nitrous acid.

For by admitting the formation of the nitrous acid from the same fluids, the argument for the composition of water drawn from the complete substitution of an equal weight of water to that of the airs which disappear by combustion, no longer exists; and as the appearance of a large quantity of water in these experiments is readily explained from the precipitation of the water which is known to be suspended in these elastic fluids, or which even make a necessary part of their composition, no fact remains on which the hypothesis of the formation of water from any proportion of inflammable or vital air is grounded. The fundamental experiment of this doctrine, namely, the equal substitution of water, and nothing but water, to the airs which disappear, being removed, the structure with all its ornaments must fall, and no other vestige will remain but the ingenuity and skill of the artist.

OF WATER IN A FLUID STATE.

Water is considered as a pellucid, colourless fluid, tasteless, and without smell, nearly incompressible, and elastic only in a small degree. It adheres to the substance of most bodies, but penetrates and incorporates with a still greater number. It extinguishes flame. It is capable of passing through various states of aggregation, from the solidity of ice to the tenuity of vapour.

Many have considered ice as the natural state of water, and the fluidity thereof as a state of violence, or as ice kept in continual fusion, and returning to its former state, when deprived of a certain quantity of fire. Were you to define lead and water, you would call one a solid, the other a fluid, esteeming

these their natural conditions. Yet if water be not acted upon and combined with a certain quantity of fire, it becomes a solid. We call that state natural which falls immediately under our observation. If we had lived in Saturn, we should have given but one name to ice and water, although we might now and then have seen it liquified in summer; and, on the other hand, had we been born in Mercury, we should have deemed lead a fluid.

The particles of water, though moveable amongst themselves with the greatest ease, yet adhere together with a certain force; thus a drop of water remains suspended at the end of the finger, although the inferior particles only touch particles of the same fluid. This adherence of the particles prevents small needles, or very thin plates of metal from sinking therein, as they resist division more than the excess of the specific gravity of these bodies over a relative volume of water.

Water can only be compressed in a very small degree, so small that it may in general be considered as incompressible, as will be evident to you by considering the Florentine experiment which I have already mentioned to you. That it is, however, compressible in a small degree may be proved by an easy experiment: put water into a bottle with a stem nicely graduated, observe the degree at which it stands, and place the bottle under the receiver of an air-pump, and exhaust the air therefrom; when the pressure of the air is removed, the fluid will rise a little.

We have no fluid more subtile and penetrating than water, except fire; it enters into the minutest particles and pores of matter, the finest vessels of animals, and the smallest tubes of plants, and will pierce through substances which will detain air itself. This penetrative power of water, together with its smoothness and lubricity, renders it a fit vehicle

for the easy conveyance of the nutritious matter of all bodies.

It enters into the composition of all the substances belonging to our earth. There is probably no substance, whether animal, vegetable, or mineral, without it. Every being with life, in a great degree lives by it; and whatever grows, through it receives its growth; and wherever it enters, according to the economy of Providence, it promotes and sustains life, preserving all material nature in their proper classes of existence. It bears a part in the formation and decomposition of all the mineral kingdom. It is necessary to the free exercise of the functions of the animal body, and hastens and facilitates the destruction of both vegetables and animals as soon as they are deprived of life. But whether you consider it as productive of health to animals and vegetables, as requisite to the beauty and existence of the earth, or as one of the great powers by which God works in the sustentation and action of the whole universe; you cannot but admire the sublime propriety with which, as a sensible image, it is used in the sacred scriptures, to represent divine truth, and the holy influence of our God and Saviour.

PRESENCE OF WATER IN THE ATMOSPHERE.

So great is the necessity, use, and importance of this fluid in all things, that some ancient philosophers were impressed with a notion of its being the first principle of universal life. It seems to be universally diffused; and it will be easy to convince you of the great quantity contained in the air. You may be said to walk in an ocean; the water indeed of this ocean does not become the object of our senses, we cannot see it, nor, whilst it continues thus sustained in the air, do we feel that it wets us; but it is still

water, though it is neither visible nor tangible; just as sugar, when dissolved in water, is still sugar, though we can neither see it, nor feel it. Some are puzzled to find water enough to form an universal deluge;* to assist their endeavours it may be remarked, that were the whole precipitated which is contained in the air, it might probably be sufficient to cover the surface of the whole earth to the depth of above thirty feet. If a bottle of wine be taken out of a cool cellar in the hottest and driest day of summer, its surface will soon be covered with a thick vapour, which when tasted appears to be water. This watery vapour cannot proceed from any exudation of the wine through the pores of the bottle, for the glass is impervious to water, and the bottle remains full, and when wiped dry it is found to weigh as much as when taken out of the cellar. The same appearance is observable on the outside of a silver, or any other metallic vessel, in which iced water is put in the summer time; and it is certain, that the water which is condensed on the surface of the vessel does not proceed merely from the moisture exhaled by the breathing of the people in the room, where you may notice the experiment, because the same effect will take place if the vessel be put in the open air. Water which is cooled by the solution of any salt, or even spring-water which happens to be a few degrees colder than the air, produces a similar condensation of vapour on the outside of the vessel in which it is contained. These, and other appearances of the same kind, are to be explained on the same principle. When warm air becomes contiguous to the outward surface of a vessel containing cold liquor, the fire by which the water is suspended in the air, quits and passes through the vessel into the liquor, to restore it to the temperature of the

* *Watson's* Chemistry, vol. iii. p. 87.

place, and the water ceasing to be suspended in the air, attaches itself to the surface of the cold vessel.

Another method of proving the existence of water in the clearest air, is to observe the increase of weight, which certain bodies acquire by exposure to the open air. Dr. *Watson*, Bishop of Landaff, put into the open air eight ounces of salt of tartar, which had been well dried on a hot iron; the day was without a cloud, the barometer at thirty inches. In the space of three hours, from eleven, to two in the the afternoon, the salt had increased two ounces in weight: in the course of a few days its weight had increased to twenty ounces; it was then quite fluid, and being distilled, it yielded a pure water, equal in weight nearly to the increase it had acquired from the air. Strong acid of vitriol is another body which absorbs humidity strongly from the air. An ounce of this acid has been observed to gain in twelve months above six times its own weight.

The increase of weight experienced by the human body, in many cases from the water which the pores of the body suck in from the air, is another very sensible proof of the great quantity of water suspended in the air. The Bishop of Landaff mentions, among many instances, one of a lad at Newmarket, a few years ago, who, having been almost starved, in order that he might be reduced to a proper weight for riding a match, was weighed at nine o'clock in the morning, and again at ten, and was found to have gained near thirty ounces in weight in the course of the hour, though he had drank only half a glass of wine in the interval. The wine probably stimulated the action of the nervous system, and incited nature, exhausted by abstinence, to open the absorbent pores of the whole body, in order to suck in some nourishment from the air. It is well known, that persons who go into a warm bath, come out several ounces heavier than they went in, their bodies

having imbibed a correspondent quantity of water. Part of the utility of medicated vapour-baths depends on this principle of imbibition by the pores.

There is a circumstance of importance concerning the human frame, which seems to have escaped the attention of most physiologists, namely, the nature of animal moisture, and the means by which it is supported and kept up. I have shewn you in this Lecture what a quantity of moisture the human frame will take from the air; and this might have been supported by a greater variety of facts, if there had been any further necessity for proof. There are several considerations independent of these facts, which will of themselves lead you to conclude, that animal moisture cannot be altogether supported or accounted for by what is received internally, as meat and drink; and you will be led to think that the greater part is received from the atmosphere, and that it is probable that the human frame has a power of decomposing some of the aerial fluids which abound in the atmosphere, and procuring water from them.

The considerations alluded to above, are, that the fluids constitute more than half the bulk and matter of the animal frame; that the basis of these fluids is water; that they have a strong vaporific tendency, and are continually heated to 96 degrees; that a vast surface is exposed to the drying power of the air, not only the whole external surface, but that also of the lungs; and that every vital fibre and particle is not only exposed to this heat, but also to the motion arising from the rapid circulation of the system.

If to all these circumstances, we take in the great heat to which the body is exposed in warm climates, I think we may with little hesitation say, that if the same quantity of water, that is contained in the human frame, were exposed to as large a surface of air,

more than one half would be evaporated in twenty-four hours; for you are to consider that moisture can transpire through our skin, and that the skin is always moist, and is continually acted upon by animal heat, the air, and the general circulation; and that without a continued and successive supply of moisture, the skin would be quite parched up.

Add to this, the immense discharges which are constantly issuing out of the human system, by insensible perspiration, by the great discharges from the lungs, by the natural evacuations, by urine, saliva, &c. Take these altogether, and I think it will be impossible for you to conceive these are all supplied by the mouth.

Mr. *Harrington* says, that he has often in winter examined his evacuation by urine, and found it to exceed in quantity the moisture received into the system by the mouth. Whence then could the superabundant quantity arise? and what supported the other evacuations? what under a heat of 96° kept every minute part moist, soft, and pliable? Many more facts might be adduced in support of this opinion; but for them I must refer you to your own observation and Mr. *Harrington*'s work.

OF WATER AS MIXED AND COMBINED WITH BODIES.

You may consider the water that is in bodies in two states, either that of simple mixture, or that of combination.

In the first state, it renders bodies humid, is perceptible to the eye, and may be disengaged from them with facility.

In the second state, it exhibits no character whereby you can discover that it is thus combined. It exists in this form in crystals, salts, plants, animals, &c.

Water existing in a state of combination, concurs in imparting to them hardness; and the transparent salts, and most stony crystals lose their transparency, when they are deprived of the water of crystallization. Many bodies are indebted to water for their fixity; the acids, for example, only acquire fixity by combining with water. Water, when mixed with earth or ashes, is formed into a vessel, which, when baked, will bear the utmost force of the hottest fire that art can contrive. Thus you see a body, whose fluid and dissolving qualities are so obvious, giving consistence and hardness to all the substances of the earth. In this state nature often unites it to bodies, with which art has not yet learned to make it enter into combination.

Pure water will, indeed, unite immediately only with a certain number of substances; but after being united with these, it becomes capable of dissolving other substances in a succession, whose limits we cannot determine, because the further we advance in the knowledge of substances, the greater reason we have for perceiving our ignorance of the number which exist distinctly, and of the intimate ingredients even of those that are known. Water is the base of all menstrua: we concentrate them to a certain point by evaporation; but beyond this point, the liquid either produces nothing but vapour, or escapes entirely. An essential part of the art of chemistry consists in the composition of menstrua, and in the precipitations operated therein: in these processes water itself often enters into new combinations. If, in his operations, the chemist falls upon any lucrative process, of which he himself is ignorant of the intimate causes, he makes a secret of it. But how many such secrets are to be found among the operations of nature? How many that will be concealed from us for ever, because the primitive substances are arrived

at a state that cannot be changed by the agents of the present operations in nature.

When water, by a succession of dissolutions, contains different substances, they may be successively pricipitated in two ways, by the dissolution of new substances, or by the emission of expansible fluids, some of whose ingredients were united with the substances in the liquid. Ancient chemists knew scarce any thing of this last process, nor of the various combinations of fire and light. It is to modern discoveries on these heads, that we are indebted for the present advancement of these sciences; but if the chemist, in these pursuits, neglects the study of meteorology and geology, both for directing his investigations of the nature of expansible fluids, and appreciating his decisions on the intrinsic nature of substances, he will run the risk of accrediting errors by the very facts which should have separated him from them.*

Water may be considered as a kind of general cement. The stones and salts which are deprived of it, become pulverulent, and fall away into a mass of shapeless dust. Water facilitates the coagulation, re-union, and consistence of the particles of stones, of salts, &c. as you also see in the operations performed with plasters, lutes, mortar, &c.

The stock of water afforded by the driest bodies is surprizing; hartshorn kept forty years, and thereby become as hard and dry as any metal, so that if struck against a flint it would give sparks of fire, upon being distilled, afforded one-eighth part of its quantity of water.

For a considerable time water was thought to be a fluid earth. The earthy residue, left after the distillation, trituration, and putrefaction of water, gave

* See *De Luc's* Letters, dans le Journal de Physique, for 1790, 1791, 1792, &c.

credit to the opinion that it was convertible into earth. M. *Lavoisier* has shewn, that this earth arises from the wear of the vessels; and *Scheele* has proved the identity in the nature of the earth with that of the vessels in which the operations were made.

In a fluid state, water combines so easily with other substances, that it is never to be found in a pure state; the most genuine is mixed with exhalations and dissolutions of various kinds. Rain water, which is a fluid of nature's own distilling, and which has been raised so high by evaporation, is nevertheless a very mixed substance, impregnated with exhalations of all kinds; salts, sulphurs, and metals are combined with it. Mr. *Chaptal*, from experiments made at Montpellier, found rain water in stormy weather more impure than that which came in gentle showers; the water which falls first is less pure than that which falls after several hours, or several days rain: that the water which fell when the wind blew from the sea to the southward, contained sea-salt, while that which was produced by a northerly wind did not contain a single particle. The water caught pouring from the tops of houses is impregnated with the smoke of the chimnies, the vapours of the slates and tiles, and with such impurities as birds and animals have deposited there. It is the same with river water; plants, minerals, and animals, all contribute their share to add to its impurities; wherever the stream flows, it receives a tincture from its channel. Of the various river waters, those of the Indies and the Thames are said to be the lightest and most wholesome.

Waters in general are supposed to be more pure as they are more soft: snow water is very soft; rain water comes next to it; spring water, though the clearest and most tempting of all to look at, is the least pure, and of all others the least fit for common use. Spring water is pure or polluted, in propor-

tion as the earth through which it streams is more or less impregnated with sulphur, salts, arsenic, minerals, &c. Those that are strained through a sandy soil, free from saline or metallic substances, are the purest. The eye is no adequate judge on this occasion: it will indeed teach you not to drink or use foul or dirty water, but it will leave you in the dark as to those contents of the water which may be suspended in it imperceptibly. Transparency is certainly a very agreeable quality in water, but cannot be relied on as a proof of salubrity, for sea-water is as transparent as that which is fresh. The water of stagnate lakes and pools is in general very impure, and may be considered as a jelly of floating insects, the whole teeming with shapeless life, growing more fruitful by increasing putrefaction, forming a mass of corruption displeasing to the sense and injurious to the health.*

The atmosphere itself may be looked upon not only as the general receptacle of all aqueous vapours, but likewise of all mineral exhalations of the steams which are constantly arising from the perspiration of whatever enjoys animal or vegetable life, and from the instantaneous putrescence of those substances when deprived of life; of the smaller seeds of terrestrial and aquatic plants, of the eggs of an infinite species of imperceptible animalcules, of the acids and of oils separated by combustion from all sorts of fuel, the matter of light, of electric effluvia, and a variety of other substances. From these sources are derived many of the impurities which have been discovered in all atmospherical water, which must vary accord-

* An implement called a filtering stone has sometimes been used for purifying water, but it is in principle quite defective. Their pores are closed up by dust or dirt, and the practice of brushing, to clean them, is equally ineffectual. Mr. *Peacock's* method, that I shall hereafter describe, is the best of any that I have yet met with. EDIT.

ing to the nature of the substances, the climate, the season of the year, the direction of the winds, and many other unknown causes.

After all, we must be contented with but an impure mixture for our beverage; and yet even this may often be more serviceable to our healths than those deemed purer. Experience alone must determine its useful and noxious qualities; such water is in general to be preferred that sits light upon the stomach, that is of a fresh, lively, agreeable taste, that boils readily, and boils garden stuff, particularly peas and pulse, quickest, and which mixes perfectly and readily with soap without curdling.

Water is purified by distillation. As it is of importance on many occasions to have very pure water, it will be necessary to point out to you the means by which it may be thus purified. The operation is performed in a vessel called an alembic; the alembic consists of two pieces, a boiler or cucurbit, and a covering called a capital or head.

The water is put into the cucurbit, from which it is raised in vapour by means of fire, and these vapours are condensed by cooling the head with cold water. The vapours thus condensed flow into a vessel designed to receive them. This is called distilled water; and is purified so far as it leaves behind it in the cucurbit the salts and other fixed principles which alter its purity. The distillation is more speedy and quick in proportion as the pressure of the air is less upon the surface of the stagnant fluid.

A true distillation is carried on every where at the surface of our globe. The heat of the sun raises water in the form of vapours; these remain a certain time in the atmosphere, and afterwards fall in the form of dew by simple refrigeration. This rise and fall of water washes and purges the atmosphere of all those particles, which, by their corruption or developement might render it infectious. It is,

perhaps, this combination of water with various miasmata which renders the evening dew unwholesome.

OF THE ORIGIN OF SPRINGS AND RIVERS.

The quantity of water raised in vapour from the ocean, has rather extravagantly been thought by some to be equal to that which is poured into the ocean by all the rivers upon earth; and they therefore suppose, that what the sea gets by the rivers, it loses by evaporation, and that thus a mutual and equable interchange is preserved; that all the rivers are supplied with water by the vapours that are raised from the sea, carried thence by the wind, condensed against the sides of mountains, where, trickling down through the crannies of the rocks, they enter the hollow places thereof, and form collections of water, from whence they issue out at the first orifice they can find, and by these means constitute springs and rivers.

There is another theory to account for springs and rivers, which refers this cause to a great abyss of waters occupying the central parts of our globe. It asserts, that all the phenomena of springs are chiefly derived from the vapours, veins, and issues of this great abyss, into which they are all returned; and that a perpetual circulation and equality is kept up, the springs never failing, and the sea by reason of its communication with the subterranean waters never overflowing.

From the earliest ages these phenomena have engaged the attention of every inquisitive mind. "The sun riseth," says Solomon, "and the sun goeth down, and pants for the place from whence he arose. All things are filled with labour, and man cannot utter it. All rivers run into the sea, yet the sea is not full. Unto the place whence the rivers come,

thither they return again. The eye is not satisfied with seeing, nor the ear with hearing." At so early a period was curiosity employed in observing these great circulations of nature. The inquiry, whence rivers are produced? whence they derive those unceasing flows of water, which are continually enriching the world with fertility and verdure? has been variously considered, and divided the opinions of mankind.* But as the two above-mentioned theories are those which generally prevail, and to which most others may be reduced, we shall only examine their merits.

"It seems almost unkind to disenchant the beauties of the prospect, which the first of the two foregoing theories presents to our minds. A romantic imagination can form nothing more striking than this unceasing rotation of waters; clouds arising from the ocean, travelling till they dash against the tops of the highest mountains, then descending feebly in little streams down their sides, entering the subterranean caverns of the earth, bursting forth into springs, and at last assembling into rivers, which carry the united torrent again to its parent ocean." This is amusing speculation; but; alas! it is but speculation, and is so pressed with difficulties, that a more perfect theory is highly desirable.

Calculation has been pressed to favour this system, and so great a quantity of evaporated water contrived to support it, that if it fell, would drown instead of refreshing our earth.

That the rain and vapour which fall upon the earth are inadequate to the solution of the phenomena, and cannot possibly account for the origin of springs and rivers, will be made evident to you from a variety of considerations. Mons. *Gualtieri*, by comparing the rivers of a country with the rains that fall

* *Goldsmith's* Hist. of the Earth, vol. i. p. 134.

upon it, has shewn, that after making more allowances than are reasonable in favour of the evaporating hypothesis, they exceed the rain in quantity: he has also shewn, that it is utterly impossible for the rain waters to keep up the continual course of rivers and springs. The waters discharged by the rivers of Italy into the sea, are to the rain which falls upon the land, as 55 to 27, that is, more than twice the quantity.

The earth is constantly moistened to a greater depth than the rain of the year will account for. Mr. *De La Hire* brought this hypothesis to the test of experiment, by examining the most essential article thereof, namely, the depth that rain and snow water did really descend into the earth. To know this, he dug a hole in the lower terrace of the observatory at Paris, and placed therein, eight feet under ground, a large leaden bason, inclined a little towards one of its angles, to which was soldered a pipe twelve feet long, which, after a considerable descent, reached into an adjoining cellar. After having covered the head of the pipe with several flints of different sizes, to prevent the orifice from being stopped, he threw in a quantity of the earth to the depth of eight feet; the earth was of a nature between sand and loam, and thus easily permeable by water. He judged, that if rain or snow water penetrated the earth to the depth that some springs are found at, which in digging wells and mines are discovered to be at all depths from 8 to 800 feet, or till they meet with the first clayey or compact stratum to stop them; that if this were the case, there would soon be a spring bursting forth through the leaden pipe into the cellar. But, on the contrary, after having kept the bason in this situation fifteen years, and the ground all the while exposed openly to all the rains, snow, or vapours, that might fall, yet he

could not observe that a single drop of water had ever passed through the leaden pipe into the cellar.

At the same time that M. *De la Hire* commenced the above-described experiment, he placed another bason about eight inches under ground, and chose a place where the rain and vapours might fall, and yet the ground be screened from the heat of the sun and the action of the wind; taking care to pull up the grass and herbs that grew over the bason, that all the water which should fall on the ground might pass uninterrupted to the bottom of the bason, wherein there was a little hole with a tube to convey the water to another vessel. In eight months, that is, from the 12th of June to the 19th of February following, no water came by the tube, and though it began to run on the 19th of February, this was entirely owing to the great quantity of snow which had fallen, or was then melting. From that time the earth in the bason was very moist, though the water would only run a few hours after raining, and it ceased running when the quantity fallen was drained off.

A year after, he repeated the same experiment, but buried the bason sixteen inches under ground, taking care that there was no grass on the ground, and that it might be screened from the sun and the wind: the effect was much the same as before, excepting that when a considerable time passed without raining, the earth would grow a little dry, so that a moderate rain coming on it would not moisten it sufficiently to make it run.

The consumption of moisture by vegetables and fruits is much greater than has been commonly supposed, or generally allowed for; so great, that all the rain that falls is not sufficient to supply them with the quantity equal to what the growth demands. Mr. *De la Hire* planted herbs on the ground over

the bason mentioned in the last experiment, and found that when these were grown up a little, the ground was so far from sending any water after rain, that all that fell was not sufficient to sustain them, but that they would droop and wither unless re-sprinkled from time to time with water. Dr. *Hales* found, that a plant in 21¼ days drew off all the water of the earth on which it grew, so that without a farther supply from beneath it would perish after that period; and yet he has made no allowance for what the earth in question perspired at the same time in vapour. These considerations, which might be supported by many more, abundantly prove, not only that rain water scarcely penetrates so far as two feet, but that the quantity which falls is not sufficient to furnish what is requisite for the growth of vegetables; so that we must call in some foreign assistance for their support.

There are springs, and those common every where, so equal and constant in yielding their water at all seasons, and which are neither affected by rains nor droughts, that we cannot suppose them to be dependent on these for causes. The Rev. Mr. *Derham** describes one such under his own inspection, which was by no means consistent with the hypothesis of rain and vapour.

There are springs also too near the summits of the highest grounds in the country, to derive themselves by descent from the water which falls on the surface of the ground, there being no declivity adequate to the purpose.

The evaporation from the sea being condensed by high mountains, and soaked in there, is by no means sufficient for the production of springs and rivers;†

* Philos. Trans. No. 289, and 313.

† Memoirs of Literature, Aug. 1725. *Jones's* Physiological Disquisitions, p. 490. *Calcott* on the Deluge, p. 174.

for whatever effect this vapour may seem to have in southern climates, and in islands placed in the middle of the ocean, it cannot fairly be applied to the springs of inland countries and northern climates. Nor have the advocates for this hypothesis considered, that where the evaporation of the day is so copious, the dews of the night which fall again on the same surface, sea or land, are nearly in the same proportion; so that so much less has been gained in this way than has been generally supposed. Dr. *Derham* shews also, that springs occur in great plenty, and are constant in their course, even in times of the greatest drought, where the country is in general very low, and there are no mountain tops to condense the vapours.

The vapours and rain fall also upon the sea as well as upon the land; and the surface of the ocean is considered to be as large again as that of the dry land: so that we may justly suppose, that two thirds of whatever is raised in vapours returns from whence it came without falling upon the dry land.

No one will deny that rain and melted snow will produce many temporary springs, and increase the discharge of rivers; but this is a partial consideration, and by no means adequate to that constant supply, and to that vast quantity of waters which are to be accounted for, and which are constantly in action.

I shall, therefore, now consider the subterraneous store,* and the vapours that arise from them. And here it is a well known fact, that we never fail to find water when we penetrate deep enough into the bowels of the earth; and the deeper we go, the waters occur in greater plenty. This does not shew as if

* Those who wish to see strong evidence in favour of these subterraneous stores, should consult *Calcott* on the Deluge, and *Jones*'s Disquisitions, p. 525.

their stores depended upon any accident at the surface, for then they would rather be diminished and fail us when we work lower, their supplies being extended according to this account in springs and rivers upon the surface: but the contrary is always the case; therefore the sources are not above, but below. This conclusion seems too obvious to be avoided. In sinking mines it is very common to break in upon veins, and sometimes large and powerful courses of water in incredible quantities, which either overflow the works, or require continual assistance to drain them.

When the earth is cut through, it yields water as naturally as the body, which abounds with vessels, yields blood when it is wounded. The deeper the wound the greater is the effusion of blood, because the largest channels lie deep, and the largest of all which feed the rest, are placed in the central parts of the body. Thus it is with the body of the earth, the effusions of water observable near the surface have their supply from reservoirs which lie deeper, and they in their turns are fed by larger and deeper, till we come to the grand repository of all, which keeps up a general communication between the waters of the land and those of the sea.

Those who have been eye-witnesses of what passes within the earth, have been generally of opinion, that steam and vapour is in continual action there, though more at some times than at others; that there is frequently a very sensible warmth at the greatest depths, and many tokens of moisture arising upwards from the lower parts *Scheuchzer*, who was very conversant in these researches, says, "firmiter persuasus sum copiosissimus ex imis montis visceribus ad cacumen sublevari caloris subterranei ope vapore aqueos." Now, as the waters of the sea are salt, while the spring waters of the land are fresh, and consequently lighter, a column of sea

water will be a counterpoise to a higher column of fresh water. If, therefore, the waters of deep seas have any communication with the land, and their weight has due effect, water may rise to any required height upon statical principles, either by running channels, or by sap and percolation; for water underneath a mass of dry sand will be choaked upwards to its surface.* Sir *Isaac Newton* tried this experiment on a tube filled with dry ashes, and found the water ascénd through them with ease. In the rocky caverns of mountains much may be effected by the slow ascent of steam, which will be condensed as it comes near to the air, and distill downwards through those cracks and chasms where it finds an outlet.

When we dig for springs in small islands, and lands lying near the sea coasts, it is common to find

* Mr. *Peacock*, architect of Finsbury Square, London, has contrived a method of purifying water by ascent, and for which he has obtained a patent. The following description is partly extracted from his pamphlet, entitled, A Short Account of a New Method of Filtration by Ascent, &c. 1793.

There does not require any arguments to prove the beneficial effects of pure soft water to the preservation of health; an useful and convenient apparatus is the chief object by which it is to be obtained. The proper materials of which vessels designed to contain water should be made, are glass, porcelain, or stone ware, and ashen wood, such as is used in dairies, &c. for large reservoirs, brick, marble, stone, in tarras, or barren lime may be the best. A wood cistern lined with lead, or a strong leaden one itself, may be sufficient, when the expense or inconvenience may render the others objectionable. The substance and dimensions of the cistern being determined, it should be divided into three compartments: the first division to receive the turbid water from the service pipe; the second to contain Mr. *Peacock*'s stratafied medium for the filtration; and the third to receive the water in its clarified state, after its ascent through the filter.

Gravel of different sizes, suitable to the several strata, are necessary to produce the filtration. Mr. *Peacock* also thinks that glass reduced to the sizes is the most proper; but should any other preferable materials be suggested, the inventor would be ready to adopt them.

Different sizes of gravel appear to me easily to be obtained, by sifting it in different sized wire sieves. Mr. *Peacock* in his work

veins of a brackish water; these are certainly derived from the sea. The water that is more remote, and at a greater elevation from the sea, becomes fresh by degrees; therefore it sweetens in its progress by percolation. Here the process is palpable. But the earth being full of open veins and fissures, and strata of loose and permeable matter, must have a communication with the sea to great distances; and where the distance is so great that the lateral supply cannot take place, those deeper communications, of which there are so many evidences, will never fail us; and where percolation cannot reach, the subterraneous vapours, which are always circulating, must have their effect.

In short, wherever you dig beneath the surface of the earth, except in very few instances, water is to

does not describe this. The various sizes of the particles of gravel, as placed in layers, should be nearly in the quadruple ratio of their surfaces; that is, upon the first layer or stratum a second is to be placed, the diameters of whose particles are not to be less than one half of the first, and so on in this proportion; and as this theory supposes the particles to be spheres, in practice it is necessary to increase the height or thickness in each stratum, as may be necessary, to correct the irregularities in their form: experience only will best determine this. This arrangement of filtering particles will gradually refine the water by the grosser particles being quite intercepted in their partly ascending with the water. The operation will be more clearly understood by the following description of the glass vessels in which Mr. *Peacock* first made his experiment.

Plate 7, *fig.* 7, represents the plan and section of three cylindrical glass vessels. A is the one to receive the turbid water, served from any cistern or other means by the pipe and ball cock at D. E is a straining cloth, to clear the water from filaments, &c. it is in the form of a bag, which may, by being fixed to a hoop, be kept on the top of the vessel. The cock may be turned, and the ball taken off occasionally. The glasses are contained in a light frame lined at bottom and about three inches up the sides with sheet lead, to form a recipient for the waste water from the cocks in the glasses. The turbid water from the vessel A, passes by the pipe G, into the lower part of the vessel B, under a spherical or conical form of grating H, which is supported by three feet I, I, I. Upon this grating is laid the several strata of gravel, or the filtering medium, to the height proper to receive the lower end of the air-pipe K,

be found; and it is probable, that by this subterraneous water springs and rivers, nay a great part of vegetation itself, are supported. It is this subterraneous water raised into steam by the internal heat of the earth that feeds plants. It is this subterraneous water that distills through its interstices, and there cooling, forms fountains. It is this that by the addition of rains is increased into rivers, and pours plenty over the whole earth.

This reasoning may be illustrated by a pleasing apparatus, which is sold in our streets by the itinerant Italians. The tube is about three feet high, and is fixed to a board, the tube near the top is globular, and will hold a large quantity of water, from whence it is continued of a less size to the bottom, where it is curved upwards, and annexed to another globe, from whence proceeds upwards another smaller tube, bent in an irregular meandering manner to the top, where it is curved as you see downwards, and is joined to the upper globe. In the in-

which pipe is supported at the top of the glass. After the remainder of the strata is placed round the pipe, in proper order, till a secure foundation is obtained for the finest stratum, which is the main agent in the percolation, and is represented at L. Upon this the others are laid, but in an inverse order, and to such an height, that the whole medium shall resist any disturbance from the pressure of the column of the water in A. The air-pipe, K, is charged to a similar height, beginning with a degree coarser than that at the bottom of the pipe, leaving out the finest stratum; whence, as the water passes from the vessel A, through G, into the cavity below H, in the vessel B, the air from the cavity, and from the interstices of those strata as lie below the end of the pipe K, is driven up the said pipe, and permits the water to rise to the pipe F, in a filtered state, and through which it passes into the vessel C, and from which it is drawn by the cock M. A portable apparatus of this kind will serve for a family of six or eight persons.

When the operation appears uncommonly languid, it will be proper to let all the vessels be as full as possible, which will be in the course of a night in its worst state, and the next morning a stop-cock, in the pipe G, may be turned, and the cock, N, opened to discharge all the water in the vessel B, together with as much of that in C, as shall be above the pipe F. By this means, the reflux of the water carries down with it all the fecundities and ob-

side of the lower globe, one part of the tube is so contracted as to form a fit passage for a spring, or jet d'eau, to arise from it. I pour red-coloured water into the tube by means of this aperture, letting it rise therein till it has filled the upper globe; the air in the lower globe will be condensed by the pressure of the water endeavouring to rise to its level, the re-action and spring of the air will impel the water you see upwards through the small tube and all its meanders, and make it fall into the upper globe, and thus cause a constant circulation as long as any water remains in the upper globe. Now, if you suppose the upper globe to represent the sea, the lower globe to represent the abyss, and the jet d'eau to be a spring breaking out therefrom into the hollow parts of the earth, and from thence continued through small winding fissures to the surface, and from the channels of the river into the sea again, the one may be allowed to be a proper representation of the other, and an experimental illustration of the possibility of such a circulation.

structions, and the degree of filtration is restored, as at first. Mr. *Peacock* says, that this cleansing is not required oftener than five or six times in a year, unless the original water comes in uncommonly turbid. This cleansing may also, at any time, in a few minutes be effected by shutting the cock at D, and opening the cock at O. All the water of the third vessel above the pipe F, together with the whole of the second vessel, down to the pipe G, would flow back, and pass through the cock O.

Fig. 8, will convey Mr. *Peacock*'s idea of plans of three vessels, made of earth, stone, marble, &c. materials, wherein the space, A, represents the bottomless tube, which is to receive the turbid water from the pipe, and discharge the air from the grating, &c. under it. B, the part in which the filtering medium is to be placed, and C, the part to receive the cleared water. The vessels of these square forms will require to be well joined or clamped together, as circular forms are not essential. Ingenious workmen can avail themselves of this hint.

For other ingenious contrivances of vessels for sea, camp, or garrison service, as well as a plan for building a filter to supply a village or district, I must refer the reader to Mr. *Peacock*'s own publication. EDIT.

OF THE SALTNESS OF THE SEA.

No sooner have we endeavoured to discuss one question, than another presents itself for our consideration, one for which philosophy has not yet found a satisfactory solution. To discover the primary cause of that peculiar bitterish saltness which characterizes sea water, has exercised the naturalists of all ages; and Father *Kircher* long since observed, that the fluctuations of the ocean were scarcely more various than the opinions of men concerning its saline impregnation. Dr. *Halley*,* who often endeavoured by weak speculations to lessen the authority of the Bible, thought he had hit upon a principle, which would discover the cause of the saltness of the sea, and carry us back almost with demonstration to the true date of the creation. He laid it down as a principle, that the water of the sea derives all its saltness from the land, that a small portion of salt is continually washed down from the land by rivers, and carried into the sea, which has gradually acquired its present quantity of salt from the long continued influx of rivers. The water which is thus carried into the sea by the rivers, is again separated from it by evaporation, nothing but fresh water rises from the sea in vapours, the saltness remains behind. The salt thus carried into the sea must for ever remain there, it must therefore be a perpetually increasing quantity, and the sea must every year become more and more salt. If therefore, says the Doctor, the increment of salt could be found for any given term of years or ages, we should then be able to work backwards by the rule of proportion, and discover the time when the sea first began to grow salt; that is, when the world began to exist. It is rather mortifying for infidelity, that the problem requires ages

* Phil. Trans. No. 344. *Watson*'s Chemistry, vol. ii. p. 93. *Jones*'s Disquisitions, p. 524.

for its solution. The idea of salting the sea with fresh water is also rather uncommon, but worthy of a sceptical philosopher. The reasoning is defective in many points. For, allowing that the sea evaporates into fresh water, and that thus the salt it contains is left behind, yet we are still no nearer than before; unless, while the sea is still losing fresh water by evaporation, you could stop all the rivers, so that no fresh water might be added in the mean time. For Dr. *Halley* maintained, as you saw before, that as much fresh water is carried to the sea by the rivers as it loses by evaporation, that the rivers therefore will all be running on, and bringing in fresh water, while the vapour is rising from the surface; thus, you see, when things are compared together, the argument will end in a cypher.

The postulatum, on which the argument is built, is itself erroneous, as it supposes the water of the ocean was fresh at the beginning of the world; and the whole inquiry seems to be after the cause of a phenomenon, which has probably no secondary cause at all.* The supposition that the water of the ocean was originally fresh, is an opinion concerning a matter of fact, which can never be proved either way; and it is surely extending speculation too far, when we attempt to explain a phenomenon coeval with the formation of the earth. The saltness of the sea is as necessary to the constitution of that element, and to the well-being of the terraqueous globe, as the redness of the blood is necessary to the improvement of the serum in the animal system. The sea is no more salt by chance, than the blood is red by chance. It is a wise provision of the Creator, that the immense body of water, which occupies more than two-thirds of the globe, should be thus salted and seasoned for its own preservation, and for

* See *Watson*'s Chemistry. *Jones*'s Physilogical Disquisitions.

the salubrity of the atmosphere; on which account the ocean is salter under the torrid zone, where the heats are more productive of putrefaction, and the saltness decreases as we approach the pole, all indicating design; and if it be true, that the agitation and ventilation of the sea is not sufficient in vast tracts and deep waters to keep it sweet without a due proportion of salt, Dr. *Halley*'s scheme would have poisoned the world.

The degree of saltness in the sea varies in the same place at different seasons, sometimes at different depths.*

Dr. *Watson* informs us, that from some experiments made in a voyage from England to Bombay, in the East Indies, that the weight of the sea water was the greatest, not precisely at the equator, but where the sun was vertical, and where in similar circumstances the heat was greatest; and that the weights of equal bulks of Thames water, of sea water at Teneriffe, and at St. Jago, were 659, 673½, 780½ grains, the proportion of which number may be expressed thus: Thames water 1000, Teneriffe sea water 1022, St. Jago sea water 1184. In general, sea water possesses about $\frac{1}{32}$ or $\frac{1}{20}$ of its weight in salt. He also mentions the following simple method of estimating the quantity of salt in sea water; a method so simple that every common sailor may understand and practise it. Take a clean towel, or any other clean cloth, dry it well in the sun or before a fire, then weigh it accurately, and note down its weight, dip it in sea water, and when taken out wring it a little till it will not drip; weigh it in this wet state, then dry it, when it is perfectly dried, weigh it again; the excess

* *Count Rumford*, in his late publication of the Propagation of Heat in Fluids, remarks, that the solution of salt which the sea holds is the grand source of heat to the air; and that the ocean is not more useful in moderating the extreme cold of the polar regions, than it is in tempering the excessive heat of the torrid zone. Edit.

of the weight of the wetted cloth above its original weight is the weight of the sea water imbibed by the cloth; and the excess of the weight of the cloth after being dried above its original weight is the weight of the salt retained by the cloth; and by comparing this weight with the weight of the sea water imbibed by the cloth, you obtain the proportion of salt water contained in that species of sea water.

Congealed sea water will, when thawed, yield fresh water. To prove this, some sea water was taken up off the North Foreland; it was exposed to a freezing atmosphere, and it afforded an ice perfectly free from any taste of salt. The specific gravity of the water produced from the melting of the ice was somewhat greater than that of distilled rain water, and somewhat less than a mixture of rain and snow water taken out of a water-tub. The degree of cold at which the sea water froze was 28½ of *Fahrenheit's* thermometer, or 3½ lower than that in which common water freezes. This difference will vary according to the quantity of salt contained in the water. The freezing of sea water was formerly practised, and is probably still so in the northern parts of Europe, with a view to lessen the expense and trouble of extracting salt from sea water.

A variety of attempts have been made in our own and other countries to procure fresh from sea water: the means used for this purpose is distillation, and the most approved methods are those of Dr. *Irving* and Mr. *Poissonier*. To give you an idea of this method, suppose a tea-kettle to be made without a spout, and with a hole in the lid in the place of the knob; then the kettle being filled with sea water, the fresh vapour which arises from the sea water as it boils, will issue out through the hole in the lid; into that hole fit the mouth of a tobacco-pipe, letting the stem have a little inclination downwards; then will the vapour of fresh water take its course through

the stem of the tube, and may be collected by fitting a proper vessel to its end: this will give you a general though imperfect idea of an apparatus for this useful purpose.

I have already mentioned to you the dissolving power of water, and, in one of the preceding Lectures, given you such reasons as will probably induce you to think, that this power is chiefly to be attributed to its combination with, and the presence of fire acting in it. Salts are the substances which it dissolves the soonest, and in the greatest quantity; it will not dissolve equal quantities of all kinds of salts, some being more soluble therein than others; all salts are more speedily dissolved in warm than in cold water. When water is saturated with any kind of salt in a definite degree of heat, it will retain that salt as long as it retains its heat; but if the heat be lessened, the transparency of the solution will be destroyed, a part of the salt will become visible, and fall to the bottom; what thus falls down will be redissolved as soon as the water regains the fire it had lost. Thus the quantity of the salt which is precipitated from the cooling of the water, will depend partly on the degree of heat in which the solution is saturated, and partly on the degree of cold to which the solution is reduced. Thus water of 80 degrees, when saturated with salt, contains more salt than it would do if it had only 70 degrees of heat; and in being cooled to 50 degrees, the precipitation will be greater in the first instance than in the second. Salt is much longer in being dissolved when it is in a compact state, than when it is reduced into a fine powder, because when it is in the form of powder it presents a much larger surface to the water than when it is one solid lump.

When salts are mixed with water, a considerable quantity of air is separated from the water, and the whole of the fluid appears muddy, occasioned by a

number of very small bubbles, which rise to the top so as to form a scum; when all are risen, the water again becomes transparent. This phenomenon should be noticed, as many have been deceived by it, especially those who have written on mineral waters; they often speak of an effervescence in them where there really is none, and the appearance of it is nothing more than the air escaping.

The more salt you add to water, the more slowly it will be dissolved; after a certain quantity it will dissolve no more; the point at which the salts cease to dissolve is called the point of saturation. The proportion of water is very different with respect to different salts. Sir *Isaac Newton* supposed, that there was an equal distribution of salt through a determined space of water; hence their deposition in regular order. The salt often requires some time before it can be so disseminated that its particles may be arranged at equal distances throughout the whole fluid; in time, however, this is effected. Throw a heavy salt, as blue vitriol, into a glass of water, it at first sinks to the bottom, and after some days begins to impart its colour and qualities to the particles of water immediately surrounding it: as that part of the water which is in contact only acts on the salt, it is soon saturated, and being thus rendered heavier, remains round the salt as an atmosphere; the rest of the water acts on this surrounding atmosphere, therefore, in a little time, another stratum will be formed, containing less salt than the former; innumerable horizontal strata will at length be formed, containing less and less salt: hence the diffusion is very slow, unless it be assisted by agitation. The vitriolic acid is used in bleaching, being diluted in the water in which the linen is steeped. The bleachers at first thought it was enough merely to throw the acid into the water; this, however, always corroded some of the linen, because the vitriolic acid always sinks to

the bottom, and remains there a long time before it is regularly disseminated. When mixed thoroughly by agitation, the salt will never separate again.

There is another phenomenon attending the solution of salts, namely, the production of cold; this we have already explained to you, and shewn that it depends on the quantity of fire absorbed to maintain and keep up the fluidity of the salt.

LECTURE XIV.

OF WATER IN THE STATE OF ICE.

I HAVE shewn you, that water is in a fluid state only on account of its combination with fire; that if it loses the fire which is thus combined with it, its particles cohere together, and form a hard substance called ice.

Water, in freezing, parts with the fire with which it was combined. If a thermometer be immersed in a vessel of freezing water, the mercury will rise some degrees above 32°, while another thermometer, in the open air, will remain fixed at or some degrees below that point; part of the fire which was fixed in the water being disengaged, escapes into the air when it assumes a solid form. A similar disengagement of fire is perceived in the crystallization of salts. On the other hand, when ice melts, it combines itself with a considerable quantity of fire, which at the same time does not increase the temperature, which you may prove by this experiment. Let there be a pound of ice at 32°, mix a pound of water at 172 therewith, and, in a few moments, the ice will be

melted, and the temperature of the mixture will be 32°; a quantity of fire, which raised the thermometer 140° (140+32=172), was absorbed by and combined with the ice to give it a fluid form; but the fire, thus absorbed, does not produce any effect upon the thermometer.

The fire, which the water absorbs, when it acquires a fluid form, is again separated from it by congelation; for if a pound of water at 32° be mixed with an equal quantity of ice at 4°, nearly one-fifth of the water will be frozen, and the temperature of the mixture will be at 32. Now, in this experiment, the ice is raised from 4° to the freezing point, that is, 28°. It is therefore plain, that by the congelation of one-fifth of a pound of water, a sufficient quantity of fire is evolved to raise a pound of ice 28 degrees: now five times 28 is 140°, so that the fire, which is extricated by congelation, is precisely equal to that which is absorbed by the melting ice. Messrs. *Lavoisier* and *De La Place* have given us this general idea of this phenomenon. "The heat, necessary to melt ice, is equal to three fourths of that which would elevate the same weight of water, at the freezing point, to that of boiling water."

The external air promotes the formation of ice; water in a close vessel freezes very slowly; but if exposed to air of the same temperature, ice will very soon be formed. A similar phenomenon is said to be observed in the crystallization of salts; many saline solutions, which will remain in that state in close vessels, display crystals almost as soon as you open the mouth of the vessel, and expose them to the contact of the atmosphere.

Gentle motion, or a slight agitation of the fluid, facilitates its conversion into ice: nearly in the same manner, some saline solutions are determined to crystallization by a slight agitation. It is probable, that the two above-mentioned circumstances

facilitate the separation of the combined fire from the water.

Boiled water may be brought to a greater number of degrees below the freezing point without congealing, than unboiled water, which contains more air.

Substances, which lessen the transparency of water, render it at the same time more difficult to be cooled below 32° without freezing, and dispose it to shoot more readily into ice.

Foreign substances chemically combined, or dissolved in water, do not take away its property of being cooled, though they alter the degree at which that property commences.

Striking the bottom of a tumbler with cooled water against a board, will produce instant congelation; when stirring the water, or shaking it in the hand, will have no effect. The most certain method of bringing on congelation is, that of rubbing a bit of wax on the side of the tumbler, but under the water; a particular roughness in the motion is felt, and a crust of ice is immediately perceived under the wax upon the glass.

These methods succeed best in proportion as the water is more cooled below the freezing point; unless the cooling amounts to four or five degrees, the friction from the wax is often in vain.

When water is cooled below the freezing point, the contact of the least particle of ice will make it instantly congeal; the glacial crystals shooting all through the liquor, from the spot where the ice touches, till the whole comes up to the freezing point. Few experiments of the minute kind afford a more striking spectacle than this, especially when the water has been cooled, nearly as much as possible, below the freezing point; both from the beautiful manner in which the crystals shoot through it, and the rapidity with which the mercury in the thermometer immersed in it runs through a space

of 10 or 11 degrees, stopping and fixing always at 32 in pure water.

The effect of ice, in hastening congelation, explains some phenomena. In a calm day, when the temperature of the air was about 20°, two vessels, with distilled water, were exposed to the cold; one of them was slightly covered with paper, the other was left open; the former bore to be cooled many degrees below the freezing point, whilst a crust of ice always formed on the surface of the other, before the thermometer, immersed in the middle of it, came to the freezing point; most probably arising from the frozen particles, which, in frosty weather, are generally floating in the air.

Oil spread over the surface of water has been found to prevent it from freezing, when other water similarly exposed has had a crust of ice upon it; the oil preventing the frozen particles from coming in contact with the water. In frigorific mixtures, the congelation is often brought on by raising the immersed thermometer a little out of the water, and lowering it again, some of the adhering water having frozen on the stem.

To insure the greatest degree of cold in water without freezing, you must cool it in a very gradual manner, keeping the cold of the frigorific mixture regularly, only two or three degrees below that of the water. Sudden cooling may be considered as one of the causes which hasten congelation. Metallic or too thin vessels are not proper for these experiments, as they transmit fire too readily. The frigorific mixture should be kept a little below the edge of the water in the tumbler, otherwise the congelation quickly begins at that place.

Fahrenheit cooled water 15 degrees below its common freezing point without freezing; M. *De Luc* to 14°. It is not improbable, that if water could be thoroughly purged of air, it might be cooled 18° be-

low the freezing point without congelation. Other fluids will bear to be cooled much more below their proper point of congelation.

When the water is nearly congealed, it augments in bulk, as we shall shew you by this simple experiment. I shall take this glass tube, marked E, H, and I, filled to E, and plunge the bulk thereof in the mixture of salt and ice; you will observe, that the water at first rises in the tube, on account of the sudden contraction of the bulb on being immerged in this cold medium; the water now contracted in its turn falls again, and will remain for some time at the same point; in a little time it will begin to expand; it has now risen to H, and will soon rise with some violence much higher; it is now got to I; the water in the bulb loses its transparency, and grows cloudy, and is freezing during the congelation; and, while the ice is hardening, the water rises in the tube; it now runs over it.

The expansive force of ice is very great, as you will be convinced by the detail of a few interesting experiments. The Rev. Mr. *Jones* made a long cylindrical metal box with a strong rim; to this he applied a cover, fitting them with great exactness, by grinding them one upon the other in a turning-lathe. He then prepared some water, first by boiling, and secondly by exhausting the air from it, which was so far effected, that when cold it did not yield the least bubble of air, on trying it with the air-pump. He filled the box with water, till it stood convex above the rim; and having applied a wet leather to the cover, he screwed it down firmly upon the box with four iron screws. In this state, it is probable, the box could not have been separated from its cover by a weight less than half a ton. He plunged the whole into a freezing mixture, in less than half an hour the water was froze into a solid mass, and as its bulk increased, the screws were forced by

the violence of the pressure, and the cover was raised up on one side a quarter of an inch above the rim.

To measure this force with more exactness, the same gentleman made another experiment, using the same box, and filling it as before with water purged of its air, and being covered, but not screwed down; it was placed upon an oaken pedestal, which had for its base a flat hewn stone of about a foot square. The shorter arm of a very strong lever was made to press upon the cover; this lever was compounded with two more to increase the power; at the extremity of the longest arm of the most remote lever a cord was fastened, which ran over a pulley, and had a weight of 28lb. by all these combined, the cover of the box was pressed with a force of above 2296lb. while it was so pressed down, the water within it was froze, and the agent by which the water was congealed overcame the whole force of the machine. The experiment, however, was not complete; for when the water began to freeze, and the cover of the box to be raised from the rim, the ground yielded under the pressure, and the flat stone, which served as a base to the pedestal, sunk a little below its first position; by this means the force was at first spent upon the ground, and did not take place in the machine till the ground would give way no more. It was, however, so sensibly perceived in the machine as to prove, that it was at least superior to one ton two hundred and ninety-six pounds. The box contained $5\frac{6}{10}$ cubic inches. May not this force proceed from fire, not as giving, but as restoring an equilibrium, which has been interrupted? For light and fire may have powerful effects in nature, where they give no sensible heat.

By the expansive force of ice, *Huyghens* burst an iron tube of half an inch in thickness. In the ex-

periments of the Academy del Cimento, bomb-shells and the strongest vessels, being filled with water, were burst in pieces by the fluid on its congelation.

When water is congealed into ice, a great number of bubbles are produced and imprisoned in it; as these bubbles are produced in the act of freezing, they extend the bulk of its water, and render the ice specifically lighter, and capable of floating thereon. That these bubbles are, in a great measure, the causes of this expansion, is clear from the experiments of *Marriotte* and *Mairan*, who found ice made with water, well purged of air, sensibly heavier than that formed from the same quantity of common water. According to *Mairan*, ice formed af water, purged of air, exceeded $\frac{1}{22}$ in bulk the volume of water which formed it; while ice made from water, not purged of air, exceeds the water one-ninth or one-tenth in bulk, therefore floats with about one-tenth part of its thickness out of, or above the water that bears it. From hence you may infer the amazing thickness of the ice in the Northern Seas, where the portion above the surface is higher than the masts of the tallest vessels.

When a tract of ice in strong masses is spread over the ground, and other ice continues to be formed underneath, where there is not room for its expansion, as in the glaciers of Switzerland, the ice underneath sometimes expands with such force as to rend the superior strata with violent explosions. In the frosty climates of the polar regions, these explosions are frequent, and sometimes as loud as a cannon.

The expansive force of ice is applied on several occasions to save the labour of man, and perform such things as are beyond the reach of art. Blocks of slate-stone, which is formed in thin plates, or strata, not separable by a tool, are taken out of the quarry and exposed to rain, which soaking into the

pores of the stone is there frozen into ice, which, by its expansion, breaks the stone into thin plates. In the iron works, they sometimes, in order to break an old bomb-shell, fill it with water, then fasten up the vent and expose it to the frost, which bursts it into pieces without farther trouble. If you expect, therefore, that any liquor will freeze, and wish to preserve your vessel, leave room therein sufficient for this accidental explosion.

The effects of this expansion are observable in a thousand phenomena. Trees are burst, rocks are rent; walnut, ash, and oak-trees are sometimes cleft asunder, and this with a noise like the explosion of fire-arms.

Nor are the effects of extreme cold less wonderful; metallic substances will then blister the skin like red-hot iron; the air, when drawn in, hurts the lungs, and excites coughing.

When the French mathematicians wintered at Tornea, in Lapland, the external air, when suddenly admitted into their rooms, converted the moisture of the air into whirls of snow. Their breasts seemed to be rent when they breathed it, and the contact of it was intolerable to their bodies; and the aqueous parts of spirit of wine, which had not been highly rectified, burst some of their thermometers.

Extreme cold often proves fatal to animal life; 7000 Swedes perished at once in attempting to pass the mountains, which divide Norway from Sweden. In cases of extreme cold, the person attacked first feels himself extremely chilly and uneasy, he begins to turn listless, is unwilling to walk or use the exercise necessary to keep him warm, and at last turns drowsy, sits down to refresh himself with sleep; but wakes no more. An instance of this was seen at Terra del Fuego, where Dr. *Solander*, with some others, having taken an excursion up the country, the cold was so intense as to kill one of their com-

pany. The Doctor himself, though he had warned his companions of the danger of sleeping in that situation, yet could not be prevented from making that dangerous experiment himself; and though he was awaked with all possible expedition, his body was so much shrunk in bulk, that his shoes fell off his feet, and it was with the utmost difficulty he was recovered.

In those parts of the world, where vast masses of ice are procured, the accumulation thereof by absorbing the fire from the atmosphere, occasions great sterility in the neighbouring countries, as is particularly the case with the islands of Iceland, Greenland, Statenland, &c.

Ice is subject to a constant diminution of its weight when exposed to the common air. Mr. *Boyle* exposed two ounces of ice to a sharp freezing air a little before midnight, and found it in the morning diminished ten grains in weight. In long continued frosts, the ice formed in ponds, and other small collections of water, is sensibly diminished every day, and often wholly evaporated; and a fall of snow may be seen considerably wasted in a few days in the severest season. The principal cause of this loss of weight seems to be the incessant action and abrasion of the air upon the surface of the ice.

Notwithstanding this loss of weight to which both ice and snow are subject in the coldest weather, and the thaw which they experience in the hottest, some have doubted, whether the quantity of congealed water be not an increasing quantity. A philosopher,* well acquainted with the nature of the Alps, expresses himself upon the subject in the following manner: "One cannot doubt concerning the increase of all the glaciers of the Alps; their very existence is a proof, that, in preceding ages, the quan-

* M. *De Luc.*

tity of snow which has fallen during the winter, has exceeded the quantity melted during the summer. Now, not only the same cause still subsists, but the cold, occasioned by the mass of ice already formed, ought to augment it still farther, and thence more snow ought to fall, and a less quantity of it be melted.

Though this be admitted, it by no means follows that there is an annually increasing quantity; for, besides the heat of the air in summer, there is another cause, which tends to prevent any indefinite augmentation of congealed water—the internal heat of the earth. The general heat of the springs of water situated deep in the bowels of the earth is 48 degrees; in mountainous countries it may be somewhat less, but sufficient notwithstanding for the purpose here mentioned. When the snow incumbent on any spot of ground is but thin, it may so far cool the earth, that the internal heat may not be able to dissolve it; but when the bed is thick enough to protect the earth from the influence of the atmospherical cold, that surface of the earth may, even in the coldest winters, receive more heat from the earth than cold from the atmosphere, and be therefore dissolved at all seasons of the year.*

This reason is corroborated by fact; for it is said that streams of water issue from the bottom of the glaciers in the Alps, in the greatest severity of winter; so that whether the internal heat of the earth be admitted or not, as a cause sufficient to explain the phenomenon, a constant thaw of the ice or snow, which is contiguous to the surface of the earth in the Alps, cannot be denied; and this, added to other causes, may render it probable, that the quantity of congealed water has its limit, even in the coldest country.

* *Watson's* Chemistry, vol. iii. p. 184.

Ice appears to be a kind of confused crystallization. Mr. *De Mairan* observed, that the needle-formed crystals of ice unite in an angle of 60 or 120°. If a piece of ice, which contains water in its internal part, be broken, the water runs out, and the internal cavity is found to be lined with beautiful tetrahedral prisms. These prisms are often articulated and crossed. When it snows at Moscow, and the atmosphere is not too dry, the air is observed to be loaded with beautiful crystallizations regularly flattened, and as thin as a leaf of paper. They consist of an union of fibres which shoot from the same center to form six principal rays; these rays divide themselves into extremely small blades. Mr. *Macquart* has observed several of these flattened radii, which were ten lines in diameter.

Hail and snow are modifications of ice. Hail is probably produced by a sudden disengagement of the fire by which water is rendered liquid, and is generally accompanied by thunder. Hail, snow, and ice, are wonderful images of the great operations in nature; and if your senses had not acquainted you how these things are created out of something, and are themselves only the properties of fire, air, and water, brought out of a prior state into such a compaction and creation as is called snow, hail, and ice, philosophy would have left you as ignorant of their nature, as it is of most material substances. M. *Chaptal* relates the following curious observation made by himself at Montpellier, Oct. 29, 1786. "On that day four inches of water fell at Montpellier, a violent explosion of thunder was heard about four in the afternoon, which appeared to be very near, and was accompanied by a most violent shower of hail. At this instant, a druggist, who was employed in preventing the mischief occasioned by the filtration of water through the wall, was greatly astonished by perceiving the water that came through

the wall instantly changed into ice. He called in several of his neighbours to partake of this surprize: M. *Chaptal* visited the place about a quarter of an hour afterwards, and found about ten pounds of ice at the foot of the wall: he was well assured it could not have passed through the wall, which did not exhibit any crack. Did the same cause which determined the formation of hail in the atmosphere act equally in the cellar?"

A mass of ice formed by a slow congelation, appears very homogeneous, and sufficiently transparent for a small distance from the surface first frozen; but in the interior parts, and particularly towards the middle, there is a considerable number of bubbles of air. A quick congelation spreads these bubbles indifferently through the whole mass, which becomes therefore almost opake, being composed of small parts of different densities; and the upper surface is more rough and irregular than when the congelation has been slow and gradual.

The ice of running waters is differently formed from that of standing waters; in these the surface is first froze, and thickens gradually by freezing one stratum of water after another; and it is carried on much more expeditiously than when it is in motion.

When the cold is sufficient, the water freezes on the edges of a river. The ice thus formed is, however, often broken and carried away by the current; more ice is then formed, which is again broken off, and so on. The cakes of ice thus formed, are at first very thin, and easily broken by the first shock, so that very few remain whole, but are broken in a thousand pieces. Thus in a little time the river is covered with small pieces of ice, that the least obstacle stops, floating down its stream. These by degrees, and from a variety of circumstances accumulate in size and number; and the ice thus formed is very irregular and opake, and mixed with a va-

riety of small heterogeneous substances, as bits of straw, herbs, &c. which had attached themselves to the pieces of ice. By a continual increase in size by the various obstacles to be met with in the course of a river, such as bridges, &c. these cakes are at last so joined as to cover the river. In very severe frosts and very cold climates, rivers have been known to be froze over with great rapidity. Dr. *Goldsmith* mentions having seen the Rhine frozen at one of its most precipitate cataracts, and the ice standing in glassy columns like a forest of large trees, the branches of which have been lopped away. So hard does the ice become in cold countries, that in 1740 a palace of ice was built at Petersburg, after a very elegant model, and in just proportions of Augustan architecture. It was 52 feet long, and twenty feet high. The materials were quarried from the surface of the river Neva, and the whole stood glistening against the sun with a brilliancy almost equal to his own. To increase the wonder, six cannons of ice and two bombs, all of the same materials, were planted before this extraordinary edifice: the cannon were three pounders, they were charged with gunpowder, and fired off; the ball of one pierced an oak plank two inches thick at sixty paces distance, nor did the piece burst with the explosion.

In the northern parts of the world solid bodies are liable to be hurt by the frost. Timber is often apparently frozen, and exceedingly difficult to be sawed. Marle, chalk, and other less solid terrestrial concretions, are often shattered by long and durable frosts. Metals are contracted by frost; thus an iron tube twelve feet long, upon being exposed to the air in a frosty night, lost two lines of its length. The expansion of water I have already mentioned to you. Trees are often destroyed by frost, and appear as if burnt by the most excessive heat.

Frost generally proceeds from the upper parts of a body downwards; but how deep it will reach in the earth is not easily known, as this depth will vary from a variety of causes, as the duration of the frost, the texture of the ground, &c. After a hard frost of some days, Mr. *Boyle* dug in an orchard where the ground was level and bare, and found the frost had scarce reached three inches and an half below the surface. Nine or ten successive frosty nights froze the ground in the orchard only to the depth of eight inches and an half. In a garden at Moscow, the frost in a hard season only penetrated two feet. Water, like the earth, seems not disposed to receive any very intense degree of cold at a considerable depth or distance from the air; the vast masses of ice found in the Northern Seas being only many flakes and fragments, which, sliding under each other, are cemented together by the congelation of the intercepted water.

The great power of frost on vegetables is a thing sufficiently known; but the difference between the frosts of a severe winter, and those of spring mornings, have been but little attended to; you will, however, find it a subject very worthy of your attention.

The frosts of a severe winter are much more terrible than those of the spring, as they bring on a privation of all the products of the tenderer parts of the vegetable world; but they are not frequent, such winters happening but once in an age; but the frosts of the spring are more injurious, as they are repeated every year.

In regard to trees, the great difference is this, that the frosts of a severe winter affect their wood, their trunks, and the large branches; whereas those of the spring have only power to hurt the buds.

The winter frosts happen at a time when most of the trees have neither leaves, flowers, nor fruits upon

them, and have their buds so hard, as to be proof against slight injuries of the weather, especially if the preceding summer has not been too wet. Hard frosts which happen late in the winter, cause very great injuries even to those trees which they do not destroy.

It is not the severest cold or most fixed frost that does the greatest injury to vegetables. Though this observation is directly opposed to popular opinion, it will be found not less true, nor any way repugnant to reason. It is humidity that makes frost fatal to vegetables, and therefore every thing that can occasion humidity exposes them to these injuries. It is well known, that vegetables always feel the frost very desperately in low places where there are fogs. The plants which stand by a river side are often destroyed by the spring and autumnal frosts; whilst those of the same species, which stand in a drier place, suffer but little, if at all. The low and wet parts of forests produce worse wood than the high and drier. The coppice wood in wet and low parts of common woods, though it push out at first more vigorously than that of other places, yet never comes to so good a growth; for the frost of the spring killing these early top shoots, obliges the lower parts of the trees to throw out lateral branches. Frost seldom hurts the late shoots of vine or flower buds, except when it follows heavy dews, or a long rainy season, and then it never fails to do great mischief.

Frost does more mischief on newly cultivated ground than in other places, because the vapours find an easier passage there than from other places. Trees newly cut suffer more than others by spring frosts, because they shoot more vigorously. Side shoots of trees are more subject to suffer from spring frosts, than those at the top; in general, the effects of the spring frosts are much greater near the ground than elsewhere.

On the same principles you may explain why the south sides of trees are more damaged by a severe frost than the north. Great damage is also done to the western sides of trees and plantations, when, after a rain with a west wind, the wind turns about to the north at sun-set, which is common in spring; or when the east blows upon a thick fog before sun-rising.

In the state of the atmosphere we denominate a frost, there is an intimate union between the air and the water in the air; therefore, except in high latitudes, frosty weather is generally clear. When such an union takes place, either in winter or summer, the atmosphere is inclined to absorb fire, and consequently to produce frost. Thus in clear settled weather, even in summer, though the day may be excessive hot, yet the mornings and evenings are extremely cold.

The air in frosty weather, or clear dry weather, being always ready to absorb fire from every substance in contact, must of course absorb part of that contained in the vapour, which floats in its bosom.

Though vapour is capable of becoming much colder than water without being frozen, yet by a continual absorption it must at last part with its latent fire, *i. e.* what is essential to its existence as vapour, and without which it is no longer vapour, but water or ice. When a frost has acquired a certain degree of intensity, then the vapours every where dispersed in the air give out their latent fire, the atmosphere becomes clouded, the frost either goes off or becomes milder, and the vapour descends in rain, hail, or snow, according to the disposition of the atmosphere.

TO MAKE ICE.

In many countries the warmth of the climate renders ice not only a desirable, but even a necessary

article; so that it becomes an object of some consequence to fall upon a ready and cheap method of procuring it. Though the cheapest method hitherto discovered, seems to be that by means of sal-ammoniac or Glauber's salt; yet it may not be amiss to take notice of some attempts made by Mr. *Cavallo*, to discover a method of producing a sufficient degree of cold for this purpose by the evaporation of volatile liquors. He found, however, in the course of these experiments, that ether was incomparably superior to any other fluid in the degree of cold it produced. The price of the liquor natuially induced him to fall upon a method of using it with as little waste as possible.

The apparatus for using the least possible quantity of ether for freezing water, consists in a glass tube terminating in a capillary aperture, which is to be fixed upon the bottle containing the ether. Round the lower part of the neck some thread is wound, in order to let it fill the neck of the bottle. When the experiment is to be made, the stopper of the bottle containing the ether is to be removed, and the tube just mentioned put in its room. The thread round the tube ought also to be previously moistened with water before it is put in the neck of the bottle, in order the more effectually to prevent the escape of the ether betwixt the neck of the phial and tube. Holding then the bottle by its bottom, and keeping it inclined, the small stream of ether issuing out of the aperture of the tube is directed upon the ball of the thermometer, or upon a tube containing water or other liquor that is required to be congealed. As ether is very volatile, and has the remarkable property of increasing the bulk of air, there is no aperture requisite to allow the air to enter the bottle while the liquor flows out. The heat of the hand is more than sufficient to force out the ether in a continued stream at the aperture.

In this manner, by throwing the stream of ether upon the ball of a thermometer in such a quantity, that a drop might now and then, every ten seconds for instance, fall from the bulb of the thermometer, Mr. *Cavallo* brought the mercury down to 3°, or 29° below the freezing point, when the atmosphere was somewhat hotter than temperate. When the ether is very good, *i. e.* capable of dissolving elastic gum, and has a small bulb, not above twenty drops of it are required to produce this effect, and about two minutes of time; but the common sort must be used in greater quantity, and for a longer time; though at last the thermometer is brought down by this very nearly as low as by the best sort.

The proportion of ether requisite to congeal water, seems to vary with the quantity of the latter; that is, a large quantity of water seems to require a proportionably less quantity of ether to freeze it than a smaller one. "In the beginning of the spring," says Mr. *Cavallo*, "I froze a quarter of an ounce of water with about half an ounce of ether; the apparatus being larger, though similar to that described above. Now, as the price of ether sufficiently good for the purpose is generally about eighteen pence or two shillings per ounce, it is plain, that with an expense under two shillings, a quarter of an ounce of ice, or ice cream may be made in every climate, and at any time, which may afford great satisfaction to those persons, who, living in places where no natural ice is to be had, never saw or tasted any such delicious refreshment. When a small piece of ice, for instance, of about ten grains weight is required, the necessary apparatus is very small, and the expense not worth mentioning. A small box four inches and an half long, two inches broad, and one and an half deep, contains all the apparatus necessary for this purpose; *viz.* a bottle capable of containing one ounce of ether; two pointed tubes, in case one

should break; a tube in which the water is to be frozen, and a wire. With the quantity of ether contained in this small and very portable apparatus, the experiment may be repeated about ten times. A person who wishes to perform such experiments in hot climates, and in places where ice is not easily procured, requires only a larger bottle of ether besides the whole apparatus described above.

TO PRODUCE A GREAT DEGREE OF COLD.

The power of producing cold belongs particularly to bodies of the saline class. In a paper of the Philosophical Transactions, Mr. *Geoffroy* gives an account of some remarkable experiments with regard to the production of cold. Four ounces of sal-ammoniac dissolved in a pint of water, made his thermometer descend two inches and three quarters in less than fifteen minutes. An ounce of the same salt put into four or five ounces of distilled water, made the thermometer descend two inches and a quarter. Half an ounce of sal-ammoniac mixed with three ounces of spirit of nitre, made the thermometer descend two inches and five lines; but, on using the spirit of vitriol instead of nitre, it sunk two inches and six lines. In this last experiment it was remarked, that the vapours raised from the mixture had a considerable degree of heat, though the liquid itself was so extremely cold. Four ounces of saltpetre mixed with a pint of water, sunk the thermometer one inch three lines; but a like quantity of sea-salt sunk it only two lines. Acids always produced heat, even common salt with its own spirit. Volatile alkaline salts produced cold in proportion to their purity, but fixed alkalines, heat.

If, instead of making these experiments, however, with fluid water, we take it in its congealed state of ice, or rather snow, degrees of cold will be produced

vastly superior to any we have yet mentioned. A mixture of snow and common salt sinks *Fahrenheit's* thermometer to 0; pot-ashes and powdered ice sinks it eight degrees farther; two effusions of spirit of salt on pounded ice sinks it more than 14½° below 0. This is the ultimate degree of cold that the mercurial thermometer will measure, because the mercury itself then begins to congeal; and, therefore we must afterwards have recourse to spirit of wine, naptha, or some other fluid which will not congeal. The greatest degree of cold hitherto producible by artificial means has been 80° below 0, which was done at Hudson's Bay, by means of snow and vitriolic acid, the thermometer standing naturally at 20° below 0. Greater degrees of cold than this have indeed been supposed. Mr. *Martine*, in his Treatise on Heat, relates, that at Kirenga in Siberia, the mercurial thermometer sunk to 118° below 0; and Professor *Brown* at Petersburg, when he made the first experiment of congealing quicksilver, fixed the point of congelation at 350° below 0; but Dr. *Black*, as soon as the experiment was made known in this country, observed, that in all probability the point of congelation was far above this. His reasons for supposing this to be the case were, that the mercury descended regularly only to a certain point, after which it would descend suddenly and by starts 100 degrees at a time. This, he conjectured, might proceed from the irregular contraction of the metal after it was congealed; and he observed, that there was one thermometer employed in the experiment which was not frozen, and which did not descend so low by a great many degrees. Experience has since verified his conjecture; and it is now generally known, that 40° below 0 is the freezing point of quicksilver.

Since the discovery of the possibility of producing cold by artificial means, various experiments have been made on the efficacy of saline substances in this

way; all of which, when properly applied, are found to have a considerable degree of power. Dr. *Boerhaave* found, that both sal-ammoniac and nitre, when well dried in a crucible and reduced to fine powder, will produce a greater degree of cold than if they had not been treated in this manner. His experiments were repeated by Mr. *Walker*, apothecary to the Radcliffe Infirmary in Oxford, with the same result: but he found, that his thermometer sunk 32° by means of a solution of sal-ammoniac, when *Boerhaave*'s, with the same, fell only 28°. Nitre sunk it 19°. On mixing the two salts together, he found that the power of producing cold was considerably increased. By equal parts of these salts, he cooled some water at 22°, the thermometer standing at 47° in the open air. Adding to this some powder of the same kind, and immersing two small phials in the mixture, one containing boiled, and the other unboiled water, he soon found them both frozen, the unboiled water freezing first.

The most remarkable experiment, however, was with spirit of nitre poured on Glauber's salt, the effect of which was found to be similar to that of the same spirit poured on ice or snow; and the addition of sal-ammoniac rendered the cold still more intense. The proportions of these ingredients recommended by Mr. *Walker*, are, concentrated nitrous acid, two parts by weight; water, one part; of this mixture cooled to the temperature, 18 ounces; of Glauber's salt, a pound and an half avoirdupois, and of sal-ammoniac, 12 ounces. On adding the Glauber's salt to the nitrous acid, the thermometer fell from 50° to —1°, or 52°; and on the addition of the sal-ammoniac, to —9°. Thus Mr. *Walker* was able to freeze quicksilver without either ice or snow, when the thermometer stood at 45°. For the experiment, four pans were procured of different sizes, so that one might be put within the other. The largest of

these pans was placed in a vessel still larger, in which the materials for the second frigorific mixture were thinly spread in order to be cooled; the second pan, containing the liquor, *viz.* the vitriolic acid properly diluted, was placed in the largest pan; the third pan, containing the salts for the third mixture, was immersed in the liquor of the second pan, and the liquor for the third mixture was put into wide-mouthed phials, which were immersed in the second pan likewise, and floated round the third pan; the fourth pan, which was the smallest of all, containing its cooling materials, was placed in the midst of the salts of the third pan. The materials for the first and second mixtures consisted of diluted vitriolic acid and Glauber's salt; the third and fourth, of diluted nitrous acid, Glauber's salt, and sal-ammoniac, in the proportions above-mentioned. The pans being adjusted in the manner already described, the materials of the first and largest pan were mixed: this reduced the thermometer to 10°, and cooled the liquor in the second pan to 20°, and the salts for the second mixture, which were placed underneath in the large vessel, nearly as much. The second mixture was then made with the materials thus cooled, and the thermometer was reduced to 3°. The ingredients of the third mixture, by immersion in this, were cooled to 10°, and when mixed, reduced the thermometer to $-15°$. The materials for the fourth mixture were cooled, by immersion in this third mixture, to about $-12°$. On mixture, they sunk the mercury very rapidly, and seemingly below $-40°$, though the froth occasioned by the ebullition of the materials, prevented any accurate observation. The reason why this last mixture reduced the thermometer more than the third, though both were of the same materials, and the latter of a lower temperature, was supposed to have been partly because the fourth pan had not another immersed in it to give it

heat, and partly because the materials were reduced to a finer powder.

The experiments were repeated with many variations; but only one mixture appeared to Dr. *Beddoes*, by whom the account was communicated to the Royal Society, to be applicable to any useful purpose. This is oil of vitriol diluted with about an equal quantity of water, which, by dissolving Glauber's salt, produces about 46° of cold, and by the addition of sal-ammoniac, becomes more intense by a few degrees. At one time, when Mr. *Walker* was trying a mixture of two parts of oil of vitriol and one of water, he perceived, that at the temperature of 35°, the mixture coagulated as if frozen, and the thermometer became stationary; but on adding more Glauber's salt, it fell again in a short time: but less cold was produced than when this circumstance did not occur, and when the acid was weaker. The same appearance of coagulation took place with other proportions of acid and water, and with other temperatures.

It is observable, that this effect of Glauber's salt in producing cold, took place only when it was possessed of its water of crystallization; and thus the mineral alkali also augmented the cold of some of the mixtures: but when the water of crystallization was dissipated, neither of them had any effect of this kind.

AN ABSTRACT OF M. DE LUC'S VIEW OF GENERAL CHEMISTRY, DEDUCED FROM CONSIDERING THE CHANGE OF ICE INTO WATER, AND WATER INTO ICE.

There is no phenomenon more important than the change of ice into water, and of water into ice. Though I have already considered this phenomenon, I shall here again, after M. *de Luc*, analyze it more

particularly, in order to shew you, that it includes the important basis of general chemistry. The various operations of chemistry may be reduced to the uniting or separating of substance: their general immediate cause arises from the different tendencies of the particles which compose those different substances: and the changes which happen in these phenomena are produced by the changes that the particles undergo in their composition. Now, as the phenomena of water and ice include all these different kinds of modifications, they will furnish you with a clear and very important idea of the kind of change, which is the source of chemical phenomena.

Now, with respect to ice: 1. Its particles cannot be separated without a sensible effort. 2. When broken, the portions thereof, although brought within the smallest possible distance of each other, shew no tendency to unite. 3. When fragments of ice are laid in heaps, the respective adherence of the particles, joined to their resistance to motion, makes them remain in the same position in which they have been placed. These are strongly marked chemical properties, and the substance cannot be deprived of them, unless the particles undergo an essential change.

Water, if you were only to judge of it by weight, would be ice itself, for the transformation is made without any discernible change in weight; though very great changes have taken place in the ponderable particles; for, 1. They may be separated with the greatest ease, their resistance to separation being almost insensible. 2. They have a tendency towards each other, even at a sensible distance; hence small masses, when free, coalesce, and form a spherical drop the moment they touch; and this is not the effect of gravity, but contrary to it. 3. These new particles slide so easily one over the other, that, excepting the above-mentioned small masses, they

cannot now be laid in heaps; but yield immediately to the effects of gravity, and always become level. Let us now consider how these changes in the particles of ice are accounted for. Philosophers are unanimous in allowing, that these changes are occasioned by fire, a substance without weight. The quantity of this substance that produces this effect, is sufficiently characterized by its peculiar properties; but, after this change, these properties are no longer exercised, because the particles of fire are combined with those of ice. It is this combination that occasions the chemical changes just described. Now these changes are as essential, with respect to physical principles, as any other in the art of chemistry; so that unless established facts should lead us to assign a sensible weight to other substances, which modify these effects in water, this example alone would authorize us in considering these new substances as imponderable, or without weight.

Besides the above-mentioned chemical phenomena, relative to water and ice, there is another very important one, which will serve as a point of comparison. We find from these phenomena but one ponderable substance, known by the name of water, and an imponderable substance called fire. Now, when the particles of water are in a liquid state, a state produced by their union with fire, a certain diminution in the quantity of free fire will bring them to such a minimum of distance, and arrangement in position, that they will unite in a determined form, and quit the fire which rendered them liquid: or inversely, when the particles of water are formed into ice, if the quantity of free fire interposed therein be sufficient to separate them, it then combines with these particles, and constitutes water; this may be called the fire of liquifaction.

Now every attentive philosopher must acknowledge, that these are great phenomena, brought

about by the combination of two substances, one of which is without weight; and that these phenomena are probably the general characters of a particular class. It is to be regretted, that the ponderable substance, which is common both to water and ice, has not a peculiar and appropriate name, for this substance belongs also to aqueous vapours. M. *de Luc* was once inclined to distinguish it by the term humor. You will, I hope, be careful to distinguish the cases in which I shall speak of water as a substance modified neither by fire, nor by any other substance. To render you more attentive to this distinction, I shall sometimes use the word humor.

The foregoing analysis will enable you more clearly to comprehend the nature of menstrua, a class of substances of which the knowledge is very important. I shall confine myself to a few instances.

The name of acids has been given to liquid substances, which seem to be nothing more than water joined to certain imponderable particles. Thus acid liquors are to be distinguished from the acids themselves.

The general phenomena of acid liquors are the affinities exercised by their particles, as well amongst themselves as upon other substances. But water, considered here as humor, being united to fire, exercises certain affinities, as well in itself as upon other substances: other particles, therefore, as imponderable as fire, may produce such changes therein, as may alter, in some respects, its natural affinities; and we are authorized to think, that this is the case, unless the supposition be contradicted by facts.

To see this, let us examine the formation of acid liquids, and also their different products. Now, when acid liquids are formed, we have every reason for supposing the presence of water, either in the solid or liquid substances employed, or in the vital or

atmospheric air, which on decomposition is joined thereto. Those who adopt the hypothesis of M. *Lavoisier* may object to the presence of water in these airs: for in the combustion of sulphur, or phosphorus, &c. they consider vital air as the acidifying principle, and the substances as acidifiable bases. But this supposition is neither necessary nor natural. It is not necessary, because the phenomena may be as well explained without it. If there be a sufficient quantity of vital air, all that we perceive is, the production of an acid liquor; *i. e.* according to our opinion, a quantity of water whose particles are united to an acid. Now, if water is the ponderable part of all aeriform fluids, an hypothesis which is sufficient to account for every chemical phenomenon, and is the only one that accords with meteorological phenomena; it is easy to conceive, that on the decomposition of vital air, a quantity of water united to acid particles may be liberated. For example, we consider sulphur as containing an acid, phlogiston, fire, water, and other unknown ingredients, combined together in a solid form, of which I shall treat hereafter: that vital air contains water and fire, which at a certain degree of heat acquire the power of uniting with phlogiston; and thus you perceive, as far as it is possible to see into nature, why, on the decomposition of these two compounds by combustion, a liquor results, in which the particles of water are united to an acid, distinguished by the name of vitriolic.

With respect to the French hypothesis, it should seem, that every man would consider himself as relieved of a burden, when he found it no longer necessary to admit a substance, which, without being acid itself, was yet the cause of acidity. Further, though acids may be supposed to exist, they can only act in liquids, or expansible fluids. So that these operations, instead of furnishing us with an acidification,

of which we have no conception, leads us only to consider these acids as liberated, and enabled to act by their union with a liquid.

It may therefore be asserted, with confidence, till something more solid is produced, that the operations by which acid liquids are formed, consist in liberating water and the acid particles from their preceding combinations; and thus to produce water charged with certain particles to which no weight can be assigned, and which are only discerned by their properties in the substances containing them. Now, as soon as the water thus modified receives the fire of liquifaction, its particles being free to follow their tendencies, enter into new combinations, by means of the acid particles from which it has received these new faculties. Let us then pursue these particles in the exercise of their acquired tendencies; and first in the phenomena of the congelation and liquifaction of the liquids they form.

The water of acid liquors preserves its general faculty of existing, according to the difference of temperature, in a solid or liquid form; but it has undergone two changes, one, by which its particles do not abandon the fire of liquifaction, but by a greater diminution of heat; by the other, when they do abandon it and unite, they assume a different arrangement. Here we only perceive different specific characters of the same generical modification. The particles of water (humor) whether alone, or whether combined with an acid, can unite with the fire of liquifaction; but in the last state they preserve it in a lower degree of heat; and when they lose it, instead of grouping themselves like pure water in a form in which their volume is increased, they, on the contrary, occupy somewhat less room.

By the experiments of Mr. *M^c Nab*, at Albany, in Hudson's Bay, we find, that spirit of nitre under-

goes, according to its degrees of acidity, two kinds of congelation, distinguished by Mr. *Cavendish* into the aqueous and spirituous. In the first, the ice being produced by the pure water, swims above the rest of the liquid; in the other the liquid itself freezes, and the ice thereof falls to the bottom of the part yet liquid. In the last phenomenon the point of congelation changes with the degree of acidity, but it is far from following the laws thereof.

Mr. *Cavendish* had determined by other experiments, that the true point of congelation cannot be obtained, but by preserving therein some icicles of a former congelation. It is thus that the points of congelation in the following table were determined: the degrees of acidity of the spirit of nitre are expressed by the quantity in weight of marble it was able to dissolve, compared with its own weight. The thermometer used was on the scale of *Fahrenheit*; the correspondent terms are the results of experiments, reduced to a regular series of degrees of acidity.

Spirituous Congelation.

Degrees of acidity.	Point of congelation.
0.568	—45.5
0.538	—30.1
0.508	—18.1
0.478	— 9.4
0.448	— 4.1
0.418	— 2.4
0.388	— 4.2
0.358	— 9.7
0.328	—17.7
0.298	—27.7
0.243	—44.2

Aqueous Congelation.

Degrees of acidity.	Point of congelation.
0.243	—44.2
0.210	—17.0

beginning of the aqueous congelation.

From these phenomena, analyzed according to M. *de Luc*'s theory, it appears, 1st, That by a degree of acidity =568, fire may remain combined with the particles of water (humor) even as low as —45.5 of *Fahrenheit*. 2dly, That as the degree of acidity is successively weakened, the particles of water acquire the faculty of uniting at higher temperatures, and of quitting the fire of liquifaction; but this progress towards a maximum, which is at a degree of acidity nearly a mean between the two terms of spirituous congelation, the acidity is then 418, and at —2.4 the particles of water unite. 3dly, The acidity continuing to be diminished to 298, the particles of water lose successively the power of approaching without ceasing to be liquid, so much so, that at this point fire is ready to combine with them at 22.7. 4thly, This loss of power relative to the particles of water, continues till the acidity is reduced to 243, and at this point the fire of liquifaction does not quit them, but at the temperature of —44.2, which very nearly corresponds to what happened at the greatest acidity 568: but now a new phenomenon takes place; the particles of water being less charged with acidity, again tend to crystallize in their own way, and those that are most favourably disposed thereto, quit their acid and the fire of liquifaction, and become common ice. Lastly, from this point, the more the acidity is diminished, the sooner the particles of water unite, so that when the acidity is only 210, ice (of pure water) was formed at the temperature of 17. These singular phenomena are not peculiar to the spirit of nitre, they have been also observed in the spirit of vitriol, as may be perceived by the result of experiments formed into a table.

Strength.	Freezing point.
977	+1
918	—26
848	+46
846	+42
758	—45

From hence we may conclude, that oil of vitriol has not only a strength of easiest freezing, but even a strength superior to this; it has another point of a contrary flexure, beyond which, if the strength be increased, the cold necessary to freeze it again begins to diminish. From the weakest degree of the acid 758, to that of 848, there is an increase of 91° in the freezing point. The acidity increasing to 918, the freezing point falls again to 72°, and rises 27, when the acidity becomes 977.

Now there are in these phenomena of acid liquors no symptoms which suffer us to consider them as simple substances, ponderable in their nature, or as compounds of two substances, the one acidifiable, the other acidifying, and both ponderable. According to the first of these notions, in which the acids are considered as dissolved in water, we find no point at which to stop, in order to determine their proper weight; in the water they are only perceived by their effects, in other compounds they are not discerned: thus, nothing here hinders our considering them as imponderable, if other circumstances conduct us to this conclusion. The second notion seems to exclude this supposition, because a known weight is attributed to the acidifiable and acidifying particles; but the foregoing experiments deprive this idea of all probability; it cannot explain the extraordinary changes in the freezing point, occasioned in the same ponderable substance, merely by the addition of more or less water.

But to be more particular, when the ponderable part of vital air is employed as an acidifying principle to produce an acid, is it a liquid, a substance by its nature capable of being frozen and liquified? Here the advocates for this theory leave us in the dark; we call in vain for explanation. If the ponderable part of vital air, by being joined to the ponderable part of inflammable air, produces water, can it in the same operation, the combustion of sulphur for instance, produce an acid? Here also we receive no explanation. If, in the combustion of sulphur, part of the vital air is used to form an acid, part with inflammable air to produce water, what is the ratio of the two portions? By what means shall we distinguish them? What is the acidifiable substance in sulphur, distinct from inflammable air? The partizans of the French theory are obdurate, and will afford us no explanation. If, instead of this obscure theory, you consider the water formed by the two airs to be united to an acid, the whole is readily explained, and the double flexure of the freezing point easily understood.

From the crystallization of pure water we learn, that its simple particles are of a certain form, and that they tend towards each other by certain determined sides. Now the different combinations of the acid with the particles of water may change the tendency of these to collect themselves together, and occasion the above-described flexures: how this is effected might easily be shewn by geometry, though it cannot be rendered a subject for these Lectures.

It does not appear, that the difference in specific gravity between acid liquors and water is owing to any ponderable substance added to the water; but rather to this, that the particles of water are joined to an imponderable substance, by whose means they may be brought nearer to each other without quit-

ting the fire of liquifaction. Now all the preceding phenomena confirm this theory; for they prove, in general, that the particles of acid liquors may be brought much closer together than those of water, without losing the fire of liquifaction; and you will presently see, by a very clear example, that the causes which influence the freezing point, extend their effect to the general state of liquids. I shall first, however, mention another phenomenon, which furnishes a direct proof of the supposition before us.

If you mix pure water with an acid liquor, the specific gravity of the mixture is greater than the mean of the specific gravities of the ingredients: a clear proof, that the acidity causes the particles of water to approach, following an increasing law therein; because the mean approach of the particles is greater than the mean acidity of the united masses. This is also confirmed by a simultaneous effect, that is, the sudden effect of the pressure on the free fire of the mass, which augments the heat thereof; as a bar of iron is heated by forging. The preceding remarks on acid liquors apply so naturally to alkaline liquors, that it will be unnecessary to mention them here. In neither is there any thing which leads us to think, that the difference of acid and alkaline liquors from pure water depends on ponderable particles.

From the union of acid and alkaline liquors result saline liquids, from which afterwards by simple evaporation we obtain neutral salts, that is, solids of a certain form, which do not receive the fire of liquifaction at the temperature of the atmosphere, unless we restore to the salt the water that was evaporated from it. Now, if acid and alkaline liquids are nothing but water modified by certain different particles, their solid products should be nothing more than water itself, modified by the union of these particles; and this the water of crystallization di-

rectly authorizes us to conclude. Let us then consider this phenomenon further. In some salts, after the water of crystallization is evaporated, the remaining mass is no longer capable of being liquified without an addition of water; in others, the mass may be liquified alone by a great degree of heat. Now here, we only see the modifications of the general phenomena of this class, namely, different combinations of the particles of water with certain other particles, which changes considerably their faculty of receiving the fire of liquifaction; and we even see these combinations of water may be such, that its particles refuse to receive the fire of liquifaction, in some cases without a great degree of heat; but even absolutely in other cases.

If, after salts have been reduced by evaporation to a refractory state, the water which was evaporated be restored with a small addition, the molecules of water, which form the sensible mass of the mixture, re-acquire the fire of liquifaction at the temperature of the atmosphere, and we obtain saline liquids.

Dr. *Blagden*, in his paper on congelation, has shewn, that all liquids, susceptible of being frozen, would, like water, bear to be cooled several degrees below the freezing point without congealing. Under the same circumstances, acid, alkaline, and saline liquors have the same property; a further proof, that they are the same substance differently modified.

Saline liquors quit the fire of liquifaction sooner than pure water; but attended with another circumstance, still confirming the idea of their being a modification of water. When acid and alkaline liquors freeze, the particles of water therein are so arranged as not to occupy a greater space, which you have seen was the case with pure water; but this property appears again in their compound saline liquids.

Thus when the particles of acids and alkalies separately modify the molecules of water, the moment

that these lose the fire of liquifaction, they are grouped into solids, which occupy less space than was before occupied by the molecules which compose them; but if the particles of water are modified by those of an acid and alkali, they arrange themselves as if it were pure, but only slower, exhibiting only varieties in the modification of the same substance. Oils are, probably, nothing more than water modified by imponderable substances, among which we are to reckon phlogiston.

There is no phenomenon of acid, alkaline, and saline liquids, which can lead us to assign a discernible weight to any other particles but those of pure water.

In all these phenomena we only perceive the developement of an ancient principle of chemistry, that no substance can act chemically, unless it be dissolved; for in order that the particles of any substance may obey its respective tendencies, they must have liberty to move, and this they can only have in liquids and expansible fluids. The particles of water, from their faculty of being united with fire, are susceptible of liquidity, and, when in this state, can obey either their natural tendencies, or those they may have acquired by combination. It is thus that water becomes the universal menstruum; that is, by it alone all other menstrua exist, because its particles will acquire as many various tendencies, as there are species of subtile particles to unite therewith, either separately or conjointly. Among the changes in tendency, which take place in the particles of water, there is a class of great importance in the operations of nature; namely, that which relates to their different aptitude of receiving, and of retaining the fire of liquifaction; from whence, besides different liquid states, they are capable of assuming a great variety in a solid form, the solidity depending principally on this, that the particles are not capable of being united

with the fire of liquifaction, but at a certain temperature, or by the addition of certain ingredients. Salts are, hitherto, the only solids we have considered as produced by water; with respect to these, pure water, whether liquid, or as ice, is a flux, by means of which they are fusible at the temperature of the atmosphere, nay, even at a low temperature; but conducted by analogy, we may proceed further in the abstract analysis of solids.

When you consider all the solids on the surface of our globe, as well organized bodies, as natural fossils, and examine the certain and uncertain results of our analyses, you will not be able to trace in these bodies any substances ponderable in themselves, but water and elementary earths, taking the term elementary earth in a general sense. Among the substances which are not discernible by their weight, we have light, fire, electricity, acids, alkalies, phlogiston, and the peculiar particles of certain airs. Every terrestrial phenomenon seems to announce other imponderable substances; and from hence you may conceive how many causes of this class are concealed from us by our ignorance.

Such then are the substances by which the immediate physical causes produce the phenomena of our globe; the ponderable substances are water (humor) and earths; the remaining terrestrial substances consist only of particles of different classes, but of such subtilety, that whatever be their quantity in the masses that we weigh, their weight has hitherto escaped. Water will unite with all these particles, but at different degrees, and acquires by the union different affinities, from whence immediately result various liquids, expansible fluids, and some solids, which are fusible at different temperatures of the atmosphere, either immediately, or with water for their flux. By these combinations in different states with the earths, solids are produced; on which these means

of liquifaction have no power. All these combinations can only take place in liquid water, in which they have an opportunity of exercising their affinities: and when solids are formed therein, it is in certain cases, by the addition of some substances, and the simultaneous emission of some expansible fluids. These solids are no longer solvible in the remaining fluid, and in order that it may dissolve them, they must be deprived of their additional substances, and their expansible fluids must be restored to them. Now with respect to the greater part of the solids of our globe, as well as those which were formerly formed on its surface, as those which are daily forming there, these combinations are the great secrets of nature.

The preceding analysis developes this ancient principle of chemistry, that fire is the agent of all dissolution. This proposition is true, but only mediately; for light is the first agent of every chemical operation. By light united to some substances hitherto undetermined, fire receives its existence. By fire, the particles of water (humor) receive their liquidity, that is, the power of obeying, although contiguous to each other, not only their own tendencies, but those they acquire by the addition of other particles. By these additions the particles of water are more or less disposed to retain or receive the fire of liquifaction.

Marine salt may be considered as a refractory solid, and common ice as a fusible solid. These two solids being mixed above a certain temperature, have the power of seizing in common the fire of liquifaction at all points where they touch. This is the general principle of other fusions by fluxes. For experiment teaches us, that certain solids being mixed can receive the fire of liquifaction, whence the affinities of their ingredients have an opportunity of acting. Experiment has also shewn, that in order that they may receive more easily the fire of liquifaction, or that in their common liquifaction, the solids designed to be

produced may be formed, or even separate themselves by a difference in specific gravity, they must be deprived of certain ingredients. Now here again fire comes into our aid; by its agency, and that of the atmospheric air, certain expansible fluids are formed, others are absorbed, and the solids thus torrified are ready to go in the furnace, and receive the fire of liquifaction.

ON WATER IN A STATE OF VAPOUR.

Though I have explained in my Lectures on Fire the more particular phenomena that take place in the passage of water into vapour, I have also shewn you, that water heated to 212°, when the barometer is 29½, flies off in vapour, and becomes an elastic fluid, at least 800 times more rare than air. This elastic fluid or steam is the most powerful agent that can be applied to working of engines, where great mechanical power is required. This subject being thereby rendered of the greatest importance to arts and manufactures, you will not, I hope, think your time misapplied in reconsidering the nature of this wonderful agent; the more as it will, in some respects, be exhibited under a different point of view, and with some circumstances which we did not before attend to.

The quantity of fire necessary to turn water into steam is immensely great, as you may easily convince yourselves from the operation of a common still, by observing the vast heat received by the water in the worm-tub used to condense the vapour. You may strengthen this idea by considering, that if a vessel of water be placed on a good fire, and that though you increase the power of this fire to the highest degree capable by human art, yet you cannot raise the temperature of the water above the boiling point. Now what can become of the vast accession of fire, which the water in the vessel is constantly receiving. It goes off with the steam raised from the water, and may be

again obtained from it by condensing the vapour. If you prevent the steam from flying off, as in *Papin's* digester, it will retain the heat it has acquired from the fire; where the confined water will be found so hot as even to dissolve bones, and to produce such effects as I have already described to you. Yet this fire, when combined with the vapour, is as it were neutralized and rendered, with respect to external objects quiescent.

To estimate the expansive force of water reduced into vapour, I know of no instrument so convenient as that of Mr. *le Chevalier de Bettancourt.** It consists of a vessel, A, placed upon a chafing dish B, having one opening at top, to which a curved barometer, K *g r*, is adapted, and another to which a thermometer, *t h*, is fitted, and a third with a cock, *a b*; these are, you see, so disposed, that when the cock is shut there is no communication between the interior space and the exterior air.

When the cock, *a b*, is open, and the water is not heated, the mercury will, of course, be at an equal height in each of the branches *m*, *m*. If the air be then exhausted from the large vessel A, and the cock be shut, the mercury will rise from *m* to *k* in one branch, and descend from *m* to *k* in the other; so that the water being supposed to be at the freezing point, the difference between *k* and *k* will be 28 inches.

Let the water be heated rapidly, and you will perceive the first signs of its ebullition by its striking against the vessel, which it will do with so much force as to shake the whole apparatus; at the same time the mercury in the thermometer, *t h*, will rise, and that in the barometer, K, will fall; and when the mercury is at the same height in each leg of the syphon, the thermometer will be at 212°, the pressure of the steam at

* See *fig.* 11, of *plate* 6, vol. i. I have before observed, that the Lectures on Water were originally designed to make a part of the first volume.

this temperature being an exact counterballance to the weight of the atmosphere. If you now increase the heat of the water, the mercury will rise in the branch on which the air presses, and descend in the other; the difference will depend on the temperature of the water, or increased expansive force of the steam. If you add to this difference in the two columns of mercury, the height of the mercury in a common barometer, their sum will express the height of a column of mercury, representing the expansive force of the steam. The difference in the level must be used positively or negatively, according as the thermometer is above, or under 212.

There is no occasion for two barometers; if the open end of this was sealed, it might then be filled like a syphon barometer.

With this apparatus Mr. *Bettancourt* made a variety of experiments, the results of which are given in the following table.

TABLE.

Degree of *Reaumur*'s thermometer.	Expansive force.
0	0.00
10	0.15
20	0.65
30	1.52
40	2.92
50	5.35
60	9.95
67	14.50
70	16.90
86	28.00
90	46.40
95	57.80
100	71.80
104	84.00
110	98.00

When vapour is exposed to a great heat, its bulk, as you have seen, is considerably augmented; at 212° water is only rarefied to 26; but with the same degree of heat vapour is expanded to 13 or 14000 times the volume which it occupied as water. Of this you may easily assure yourselves, by taking a glass tube with a ball at the end thereof, two inches diameter; let a drop of water pass into the ball of one line diameter; the solidity of these two spheres will be to each other as 13824 to 1. Heat the ball so as to convert the water into vapour, and it will fill the whole sphere, and force the air out of the ball, as you will find by immerging the end of the tube in water, a little warm, lest the sudden application of cold should burst the ball; and, in proportion as the vapour is condensed by cold, the pressure of the atmosphere will force the water into the ball, so as to fill it entirely; proving thereby, that the vapour had forced the air out of it, and assumed a bulk 14,000 times larger than it occupied as water.

It is impossible to give you an accurate idea of a steam-engine without a model. I shall therefore content myself, in this place, with laying before you a few of the general principles on which it acts. It has been shewn you in the Lectures on Air, that the pressure of the atmosphere, at a mean, may be estimated at 14.8 pounds avoirdupois for every square inch.

If, therefore, a vacuum be by any means made in a cylinder, which is furnished with a moveable piston, suspended at one end of a lever, or ballance-beam, the pressure of the atmosphere will press down the piston with a force proportionable to the area of the surface, and will raise an equal weight at the other end of the beam.

Water, as you have seen, may be rarefied near 14000 times, and was capable of forming a vacuum by a degree of heat capable of keeping water in a

boiling state: by increasing the heat you have also seen, that the expansive force of the steam may be rendered much stronger. The steam may be condensed, or reduced to water, by a jet of cold water dispersed among it, so that 14000 cubic inches of steam may be reduced into one cubic inch of water only, and thus a vacuum is partly obtained.

Though the pressure of the atmosphere be about $14\frac{8}{10}$ pounds upon every square inch, yet on account of the piston of the several parts, of the imperfection of the vacuum, the piston in the common engines does not descend with a force exceeding eight or nine pounds upon every square inch of its surface. In Mr. *Watt*'s improved engine, are about twelve pounds and a half upon every square inch.

The piston being pressed by the atmosphere with a force proportionable to its area in inches, multiplied by about eight or nine pounds, depresses that end of the lever, and raises a column of water in the pumps at the other end of the beam equal to that weight. When the steam is again admitted, the piston is forced up by its expansive power, and the pump rods sink; but when the steam is condensed, the piston descends, and the pump rods rise; and so alternately as long as the engine works.

M. DE LUC'S THOUGHTS ON THE STATE OF AQUEOUS VAPOUR IN THE ATMOSPHERE, AND LAWS OF EVAPORATION.

As no person has paid so much attention to meteorology and the branches of philosophy relating thereto, as M. *de Luc*, I should not think I had given you an accurate idea of this subject without laying before you the result of his experiments and observations; and I may venture to assert, that you will make very little progress in this part of philosophy, unless you are master of his principles.

M. *de Luc*'s notions concerning rain were first changed from an observation on the glacier de Buet, of a degree of dryness in the air, absolutely unknown in the valley at the same temperature. This observation, followed by others, led him finally to conclude, "that rain does not proceed from the moisture which existed in the atmosphere prior to the formation of the rainy clouds."

By experiments with his hygrometer he has shewn, that air may be entirely deprived of the immediate product of evaporation; the consequence of which is absolute dryness. The same instrument shews, that this product of evaporation has a maximum, variable with the temperature, but constant under the same temperature. The hygrometer is fixed by these two states of air; no method of drying or of moistening make it pass beyond these boundaries, which thus become the extremes of a scale, referring to a total cessation or maximum of moisture.

In the same hands, the hygrometer has served to fix our ideas of the cause by which water simply evaporated in air may be precipitated. These causes are the same with those which in air, where the quantity of water evaporated does not change, occasion an augmentation of humidity, the necessary forerunner of the precipitation of water. Experience points out two, and only two; the condensation of air, or its being cooled. Some philosophers have thought that humidity was increased by rarefying the air; forming their opinion from those experiments, where the air in a receiver, on being rarefied, produced a mist or fog. Messrs. *Wilcke*, *Nairne*, and *de Saussure* have shewn, that if care be taken to exclude from the apparatus every fresh source of evaporation, the rarefaction of air promotes dryness. The phenomena on which the contrary hypothesis is founded, arise from water left in the apparatus, and the mist is produced by the acceleration of evapora-

tion in the rarefied air, and the instantaneous cooling of the space containing the air. The water which evaporates, preserving sensibly the same heat which acted on it before, fills the receiver with vapours more dense than the maximum relative to the momentary diminution of temperature, consequently they precipitate themselves suddenly. Thus this theory corresponds with the phenomena of the precipitation of water by the rarefaction of air, which is unaccountable on the supposition of the dissolution of water by air: for, in the latter hypothesis the particles of water are united by affinity to the particles of air. But neither the theory of affinities, nor any fact concerning them, authorizes us to believe that two substances thus united should acquire a tendency to separate, because the particles of the mixture were removed to a greater distance from each other; a circumstance, which, as it lessens their tendency to each other, ought to give them a better opportunity for exercising their affinity to water.

Humidity cannot, therefore, be increased by this cause, since the augmentation of humidity would be a sign that water was separating itself more efficaciously from the particles of air. Now, in M. *de Luc's* theory, when an aqueous fluid mixed with air produces moisture therein, this moisture must be diminished by rarefying the air. And this is really the case; for there is less water in the receiver after a portion of the vapour has been pumped therefrom. The temperature is soon also re-established by the fire, which passes through the receiver to supply the place of that which was carried away with the vapour.

Rarefying the air, when the quantity of evaporated water remains the same, is therefore a cause of dryness instead of humidity. Now, with respect to the other cause of an increase of moisture, the condensation of the air, it cannot be supposed in the atmos-

phere; there remains, therefore, but one cause by which we can account for the precipitation of water which is evaporated in open air, namely cold: and from time immemorial those who have endeavoured to explain rain by this cause, have had recourse to strata of air in motion, which were more or less warm than those they met; but this explanation is also chimerical.

When, in a given mass of air, the evaporated water is at its maximum in a given temperature, if the heat be increased, the particles separate further, and the air will contain more water. If the particles are brought nearer together, the water superabounds, and the excess is precipitated. These facts are certain. Now let us suppose two strata of air of different temperatures meeting each other, each of them containing evaporated water at its maximum for the respective temperatures; the warmer stratum will lose its heat, and consequently its superabundant water; but the other stratum will acquire this heat, and be therefore capable of receiving this superabundant water.

When M. *de Luc* and his brother were at the bottom of the glacier de Buet in 1770, it had rained for some time, the valley and neighbouring mountains were imbibed with water. There was also a very great evaporation from the ground of these mountains, which was increased by the quantity of melting ice. They, however, experienced a degree of dryness unknown at the same temperature upon the plains. Two years after, returning to the same place with an hygrometer, they found that the humidity diminished as they rose; and, when they arrived at the summit where the ice was beginning to melt, they found that same extraordinary dryness, which had so much struck them on their first visit.

While they were upon the glacier, dry as it seemed to be, some clouds began to form in the stratum where they were situated; they rolled first about the mountain, but they soon were formed throughout the whole stratum, extending to a great distance towards the plains, and increasing with such rapidity, that M. *de Luc* and his brother thought it prudent to descend: the hygrometer still advanced towards dryness. Soon after their departure from the glacier, it was covered with clouds, and before they had attained their lodging, there was a heavy rain from the very stratum, which a little before was so exceeding dry; the rain continued during the whole night, and part of the next day.

M. *de Saussure* has confirmed these observations of M. *de Luc* by many more, which all tend to prove the great dryness of the atmosphere in these superior regions.

The water which is at the lower part of the atmosphere is continually evaporating and rising in the air, but this evaporation does not increase the moisture therein; for, in a dry season it goes on diminishing, the ground at last becomes dry, the vapours discontinue, and the dew ceases every where but near the water. This phenomenon does not however appear surprizing to those who imagine that the evaporated water is collected in the higher regions, where the clouds are formed. But this idea must be abandoned, for we now know that in serene weather, before the clouds are formed, and even among the clouds, the upper regions are at least as dry as the lower part of the atmosphere, in its greatest degree of dryness, at the same temperature. These clouds are not therefore formed from the moisture of the air. The immediate product of evaporation in some manner changes its nature in the atmosphere, for it does not sensibly affect the hygrometer; and its return to a state of aqueous vapour, to produce clouds and

rain, proceeds from some cause of which we are ignorant.

Of the various hypotheses to resolve this difficulty, that of M. *de Luc* is the most probable, who supposes that the aqueous vapours are turned in the atmosphere into an aeriform fluid, and that rain proceeds from the decomposition of this air. On this hypothesis it is easy to perceive why the hygrometer is not affected by the quantity of water that is often existing in the atmosphere.

The difference between water as vapour and as an aeriform fluid, consists in this; that in vapour the union of water with fire is very weak, and is easily destroyed by pressure or cold; but, by the addition of another substance, it loses these properties and becomes an aeriform fluid. There are many reasons for supposing that a variety of aeriform fluids are included in the atmosphere, which, by resisting the operations used to diminish the atmosphere, are unknown to us. Now, the operation of these, or of other substances in the air, may decompose water considered as an aeriform fluid, and thus occasion rain.*

The variations of the barometer seem naturally to lead us to some such conclusion; for, when the barometer falls as a sign of rain, it is from a change in the specific gravity of the air; but Messrs. *de Luc* and *de Saussure* have proved, that there never is a sufficient quantity of vapour in the atmosphere to occasion the difference produced by this instrument. There are many other phenomena which are not accountable on the usual principles, and conduct us to look for some further change in the theory of the atmosphere.

* The reader must be referred to M. *de Luc*'s Letters, to learn why the French theory of the decomposition of water does not apply to this case.

LAWS OF EVAPORATION BY M. DE LUC.

M. *de Luc* here, as before, considers moisture in the air as the modification of a particular fluid, consisting of water and fire, mixed with the air, but independent thereof.

He also considers evaporation, which occasions this moisture, as an operation of fire without the interference of air.

That it is an operation of fire, is plain; for every liquor cools when it evaporates, because the portion of the fluid that disappears carries away a quantity of fire from the liquor.

Mr. *Watt* has shewn, that in the ordinary evaporation of water in the open air, the quantity of heat lost by the mass, bears to the quantity of water carried away, a greater proportion than that which is found in the steam produced by boiling water. There is, therefore, no room to doubt that steam is formed in the first as in the last case.

Whenever water is in a state of evaporation, an expansible fluid composed of water and fire is produced. To this fluid M. *de Luc* gives the name of steam. I use this and vapour indifferently.

As long as steam exists, it exerts a power of pressure like air itself; but it does not belong to the class of permanent elastic fluids, as it may be decomposed either by pressure or by cooling.

There is, as you have seen, a material difference between what are called permanently elastic fluids and steam, or the vapours of water; the former will undergo every known degree of atmospheric pressure without being decomposed; but vapour is decomposed by too great a pressure. The particles of the water, being thereby brought nearer together, unite, and quit the fire, which in passing from them manifests its usual properties.

Permanently elastic fluids cannot be decomposed in vessels hermetically sealed, because they are thereby prevented from receiving the action of the bodies with which they have a greater affinity than with those which support them in an aeriform state; but steam or watery vapours may be decomposed in vessels hermetically sealed, from that tendency of the fire, with which it is united, to an equilibrium; thus, when the exterior heat diminishes, the fire quits the water to re-establish the equilibrium of temperature. If the fire becomes sufficiently abundant on the outside, it re-enters the vessel, and vapours are again formed.

As the expansive property of vapour depends, every other circumstance being the same, on fire, it is greater in proportion as the particles contain a greater quantity.

It appears, that steam is decomposed either by pressure or by cooling; because at a given temperature it has a certain fixed maximum of density, which increases with the temperature.

Thus, when the fluid is arrived at the maximum correspondent to a certain temperature, it will be decomposed, either by being cooled, its maximum being too great for this temperature, or it will be decomposed by an increase of pressure without any change of temperature; for here its density is too great for that temperature: in either case, the water is separated from the fire, which supported it as steam.

The degree of pressure or expansive force exercised by steam, or which it can support without decomposition, depends on temperature, and is proportional to its density.

Steam is formed at every temperature where a previous space permits its expansion; but no steam can be formed where it has to overcome an obstacle superior to its expansive power at that degree of

temperature; and if it be formed, because the obstacle or pressure did not exceed its power, yet if the pressure increases, or the temperature lowers ever so little, it is totally decomposed.

It is these circumstances that determine both the degree of heat at which water begins to boil, and the variations of that degree, according to the variations of pressure; for ebullition is that state of a liquid in which steam is continually formed within itself, notwithstanding the external pressure; and to produce this expansive power in steam, a certain degree of heat is necessary in the fluid, which is determined by the degree of pressure. As for the fixity of the degree of boiling water under a constant pressure, it is produced by the equilibrium between the quantity of fire which continues to penetrate the water, and that which goes off in steam; the differences which may happen in the quantity of fire that penetrates the water, having no other sensible effect than that of producing a more or less rapid formation of steam.

From hence we may perceive the difference between the phenomena of common evaporation and ebullition. Ebullition requires a determined degree of heat, because the steam cannot be formed within the water, unless it is sufficiently strong to overcome the actual pressure on the water: but in common evaporation, the steam and vapour is formed at the surface of the water by every degree of temperature; for it meets with no resistance, but what it can always overcome; it mixes only with the air, and this it expands in proportion to its quantity, in the same manner as if it were a new quantity of air.

The steam formed by common evaporation is of the same nature with that of boiling water; but, with respect to the pressure it undergoes, it is similar to that produced by evaporation under an exhausted receiver. Under the exhausted receiver,

the resistance the steam meets with is from itself, and is consequently proportional to its own expansive power. In open air, the part of the whole pressure incumbent on the steam is to that whole, as its power is to that of the whole mass, the rest of the pressure being supported by the air with which it is mixed; which proportion in the pressure steam undergoes, brings it exactly to that of the first, as is proved by experiment.

When the thermometer is at 65°, the maximum of evaporation in an exhausted receiver,* supports 0.5 inch of mercury in the short barometer gage. That the evaporation in vacuum has the same cause as in open air, is clear from the loss of heat by the liquid in this case, as well as the other: an equal pressure is also produced, and added to that of the air, when the receiver is filled with air, as will appear by the following example:

If the thermometer be still about 95, and the receiver be filled with air of the same density as that in the room, a barometer placed in that receiver will stand at the same height as in the open air. If a sufficient quantity of water be introduced for producing the maximum of evaporation, the inclosed barometer, like the gage, will rise 0.5 of an inch.

Now, as the barometer is in every case a manometer, the phenomena observed in close vessels give us a true idea of what happens to steam in the atmosphere. When steam is mixed with air, be the mass shut up in a vessel, or be it in a certain part of the atmosphere, distinct by its place, both fluids will act on the barometer, or on every obstacle, and thus against each other, according to their respective power; because no mechanical cause can produce the decomposition of steam, but by forcing its particles to come nearer each other, than is consis-

* The mean results of experiments.

tent with the temperature by which they are supported: which case cannot happen in the atmosphere, except by the accumulation of steam in some part of it; since elsewhere it only remains mixed with the air, according to its own laws, as if there were no air.

M. *de Luc* considers the whole theory of hygrology a science, whose objects are, in general, the cause of evaporation and the modifications of evaporated water, as comprehended in the foregoing propositions.

The common source of the water thus disseminated in the atmosphere, is the surface of the earth; whence in spontaneous evaporation, both in air and in vacuo, as well as in ebullition, we see water carrying off latent fire.

If the product be collected in a close space, it acts in the same manner as a new quantity of expansive fluid.

It is known by experience that an expansive fluid is really produced by ebullition, and by evaporation in an exhausted receiver; and no good reason can be assigned to shew why the cause of evaporation and its product should change in any case only by the presence of air; and on examining what may happen in open air, we find no particular cause of the destruction of that expansible fluid, or any difficulty in conceiving its dissemination in every part of the atmosphere.

Here we lose sight of steam; for watery vapours are not discernible of themselves, and it is on this account they are not perceived in the atmosphere. Mixed therewith, they are not to be distinguished from it, because they are as transparent as itself. In a vacuum they would be taken for an elastic fluid, if we judged of them only by their mechanical effects, without subjecting them to a chemical analysis. In the air, their mechanical action is as little perceivable as that of any scattered particles of air;

and we should be ignorant of their function in the atmosphere, if it were not for their property of producing moisture.*

OF VESICULAR AND CONCRETE VAPOUR.

When vapour or steam is decomposed, if it be contiguous to substances whose heat is less than its own, the fire quits the vapour, and the water is deposited on the surface of the body in the form of dew and in drops. When the heat is as low as congelation, the vapours are crystallized and deposited in regular and curious forms.

If there are no substances contiguous to the vapours in the air the particles of water unite, and form either spherical solid drops, hollow spheres, or congealed icicles.

The solid drops unite and form rain. The icicles are the first elements of snow; but as they are often very minute, and remain suspended in the air, where they produce different meteors, M. *de Saussure* ranks them in the class of vapour, and gives them the name of concrete vapour.

The existence of the hollow spheres or vesicular vapours has been often supposed, before philosophers were able to exhibit them to the senses. The simplest and most instructive manner of observing them, is to expose a cup of some warm aqueous fluid of a dark colour, as coffee or water mixed with ink, to the rays of the sun on a fine day, when the air is very calm; a cloud will rise from the fluid to a certain height, and then disappear. An attentive eye will soon discover that this cloud consists of small round grains, of a whitish colour, and detached one from the other. To acquire a more distinct idea of

* See M. *de Luc's* paper in the second part of the Philosophical Transactions for 1792.

their form, you may observe them as they rise from the surface of the liquor, with a lens of about one inch and an half focus; being careful, however, to keep the lens out of the vapours, that they may not deprive it of its transparency.

You may thus observe spherical balls of different sizes proceeding from the surface with more or less rapidity. The more delicate rise with rapidity, and soon traverse the field of the lens; the larger fall back into the cup, and, without mixing with the fluid, roll upon its surface like a light powder, which obeys every impulse of the air, and are blown from one edge of the cup to the other, even when there is no apparent agitation in the air. These globules may be seen on a sudden to begin to move, the smallest rising by an agitation of the air imperceptible to our senses, flying off and disappearing, whilst the largest remain rolling on the surface without quitting it; at other times, you see some of them, which were suspended in the air, descend to the surface, and there reel a while like pigeons on a ground fresh sown, then on the smallest agitation rise again and fly away.

The lightness of these small spheres, their whitness, &c. give them an appearance altogether different from solid globules; their perfect resemblance to the larger balls that are seen floating on the surface of the liquid can leave no doubt of their nature; it is sufficient to see them, to be convinced that they are hollow bubbles, like those blown from water and soap.

Mr. *Kratzenstein* endeavoured to estimate their size, by comparing them with an hair, and found they were twelve times smaller than the hair, whose diameter was the 300th part of an inch, and consequently one of these was only the 3600th part of the same measure.

To observe them more readily, M. *de Saussure* used a kind of eolipile, formed of two balls, *i. e.* a glass tube sealed at A, *plate* 5, *fig.* 10, vol. i. open at D; the two balls communicating with each other, and the opening or neck D. He let some drops of water pass into the ball B, and placed it over the flame of a spirit of wine lamp; spirit of wine was used that the balls might not be obscured: as soon as the water is sensibly heated in the ball B, the ball C being yet cold, you may see the vapours from the ball B enter into the ball C, and there condense themselves in the form of a cloud, which is entirely composed of these vesicles; but when the water boils in B, the torrent of elastic vapours that enters C warms this ball, and the vapour being no longer condensed, neither cloud nor vesicles are seen; it becomes perfectly transparent, and the jet proceeds from the neck B, as from an eolipile. If yon then remove the eolipile from the flame, and cool, by means of cold water, the ball C, the vesicular vapours will again appear: by placing this ball on the stage of a microscope, you may observe these vapours with the greatest convenience.

You may even sometimes be able to observe them in a fog, or in a cloud when on a hill: to this end M. *de Saussure* used a lens of one and an half or two inches focus, which he held near his eye with one hand; in the other, he held any smooth, flat, and polished surface of a black colour, as the bottom of a tortoiseshell box; bringing this towards the lens, till it was very near the focal distance thereof, he then waited till the agitation in the air brought some particles of the cloud into the focus of the lens; when the cloud was thick this soon happened, and he perceived round and white particles passing with the rapidity of lightning, others moving slowly, some rolling upon the surface of the tortoiseshell,

others striking against it obliquely, and rebounding like a ball from a wall, others fixing themselves thereto. Small drops of water might also be perceived to settle on the tortoiseshell; but they were easily distinguished from the hollow spherules by their transparency, their gravity, and their pace.

Further, clouds do not form a rainbow; it is produced by solid drops: when a cloud is not in an actual state of resolution, it does not change the form of the stars that are seen through it, for infinitely thin meniscusses do not sensibly change the course of the rays of light. But as soon as the cloud begins to resolve itself in solid drops; even without clouds, when solid drops begin to be formed in the air, the stars seen through them are ill-defined, surrounded with a diffuse light, circles, and halos; hence these meteors are the forerunners of rain, for rain is nothing more than these drops augmented or united. When the vesicular vapours are condensed by cold, the water which formed the bubble crystallizes, sometimes into hoar frost, sometimes into snow; when it does not freeze, they unite in dew or descend in rain. Many other curious properties concerning the vesicular and concrete vapours are related in M. *de Saussure*'s excellent Essai sur l'Hygrometrie.

OF MINERAL WATERS.

A full investigation of the properties of mineral waters is the subject of chemistry; but, since the discoveries of Dr. *Priestley*, it has so much analogy with philosophy, that I cannot pass it over entirely in silence.

The name of mineral water is in general given to any water which is found to be so loaded with foreign principles as to produce a different effect on the human body from that which is produced by the

waters commonly used for drink. Our ancestors were particularly attentive to procure wholesome water; it was this that determined where they would unite together, and regulated their choice of the situation of houses. *Hippocrates*, the father of medicine, was well acquainted with the influence of water upon the human frame, and affirms, that the mere quality of the usual drink is capable of modifying and producing a difference amongst men.

When we consider, that many of the ancient philosophers supposed that all things were originally derived from water, it is evident they must have had an extensive view of the operations of nature. We see that it produces dew, clouds, rain, snow, and other meteors; nor can we help observing how every vegetable, and every animal, rises out of it. When we chemically examine the materials of which animal and vegetable substances are composed, we find water to be a principal ingredient. Nothing then remains but the solid and inanimate parts of the globe; the various earths, rocks, stones, and minerals, of which the dry land and vast mass of mountains are composed, even these, the more we examine them the more we have reason to think, derive their origin from water.

In marble, calk, and lime-stone, we find evident traces of the sea; we cannot rationally think otherwise of these strata, than that water has been greatly concerned in their origin. And further, as we find these strata irregularly mixed with the hardest rocks both above and below, we must consider them as springing from the same source. On examining the rocky strata, you will find marks which plainly point out that they originate from the sea. Thus the strata of free-stone, which are very extensive, evidently shew from their appearance, that they were originally sea sand; they are divided into small strata, and are distinguished into horizontal layers, and have the

same undulated surface as the sand of the sea shore. Flinty substances seem to form the strongest objections to this system, as they resist the action of water as much as any substances in nature: but there are many phenomena in nature which shew, that calcareous earth is convertible by length of time into a flinty matter; and marine shells are not unfrequently met with, which have lost their calcareous nature, and are converted into the hardest and purest flint. In bitumen and coals we find evident traces of a vegetable origin.

The analysis of water is not only useful in a physical point of view, but also as an object of medicine, in order to determine whether any water is useful, to know those which possess medicinal virtues, and apply them to the uses to which they are suited; or to appropriate to different works and manufactories the waters best calculated for their respective purposes; to correct impure waters; and, lastly, to imitate the known mineral waters at all places, and at all times. Whether you consider mineral waters with respect to their formation, or the benefit which accrues from them, we have reason to estimate them as precious gifts of Divine Providence. But it is with these as with many other blessings, we are too often heedless and ungrateful. "How many, for whom the wonders of creation, providence, and redemption, have been wrought, that think them not worthy their attention! Angels admire and adore, where man will not deign to cast an eye, or employ a thought."

The mineral waters are divided into different heads, according to the substances they contain:

1. The acidulous, which contain an aeriform fluid, which gives these waters a briskness like that of a fermenting. This briskness is most apparent when the water is poured from one vessel to another; it

is sometimes so considerable as to burst the bottle. They redden the tincture of turnsole, and precipitate lime water.

2. An acid is sometimes found in the waters of springs, giving them a very sensible acidity; this generally arises from the vitriolic acid: this acid has, however, in general, so strong a disposition to unite with the various substances through which the water of a spring passes, that it is seldom found in a separate state in the water.

3. An alkaline salt is sometimes met with in water; this is in general the fossil alkali.

4. Neutral salts. Of these, those that are most generally found are common salt, and sometimes nitre.

5. Earthy substances. Of these the calcareous is sometimes found. There are mineral waters which contain so much calcareous earth, as to become petrifying to other bodies.

6. Earthy compounds. Thus you may often find calcareous and other earths suspended in water by means of an acid. Thus gypsum is contained in almost all waters, Epsom salt is found in great quantities, and alum is sometimes to be met with.

7. Sulphureous waters. These waters have been long considered as holding sulphur in solution; but *Bergman* has proved, that most of these waters are more impregnated with hepatic gas: this class is known by emitting the smell of rotten eggs.

8. Martial waters. These have a very astringent taste, and exhibit a blue colour by the solution of precipitate of lime. The iron is held in solution either by fixed air, or the vitriolic acid.

Sometimes the acid is in excess, and the waters have a penetrating sub-acid taste, as Pyrmont and Spa water.

Sometimes the acid is not in excess, and the waters are not acidulous.

In chemical writers you will find the method of analyzing these different waters.* When the analysis is well made, the synthesis is no longer difficult. And the imitation of mineral waters is now no insoluble problem. The processes of nature are inimitable only in those operations that are vital. In this instance we can do more than imitate, we can vary at pleasure the nature and proportion of the constituent parts, and give them, as circumstances require, more or less energy. In artificial waters the ingredients are known, while the ingredients of waters in their natural state are always unknown.

That which Dr. *Johnson* has observed of a poet is equally applicable to a philosopher. To him nothing can be useless. Whatever is beautiful, and whatever is dreadful, should be familiar to his mind; he should be conversant with all that is awfully vast, or elegantly little. The plants of the garden, the animals of the wood, the minerals of the earth, and the meteors of the sky, should all concur to enrich his mind. By him no kind of knowledge should be overlooked, he should range mountains and deserts, explore every tree of the forest and flower of the valley, the crags of the rock, the mazes of the stream, and the great wide sea, with its unnumbered inhabitants; he will find them all

—speak their Maker as they can,
But want and ask the tongue of man.

The present Lecture has afforded you fresh instances of the wonders and variety, the harmony and magnificence discoverable in the works of God. There is not, for instance, in nature, a more august and striking object than the ocean, Its inhabitants are as numerous as those on land; nor is the wisdom

* To the Appendix to this Lecture, I have added an useful and approved method, extracted from an eminent author. EDIT.

and power of the Creator less displayed in their formation and preservation, from the smallest fish that swims, to the leviathan himself. Nor is there any image which gives us a grander idea of the power and greatness of God, who hath this raging element so much under his command: hence he is represented in holy writ, as holding it in "the hollow of his hand."

There the creatures of God multiply in a much greater proportion than by land, and are maintained without the cost or attendance of man; they are a singular flock, which have no shepherd but the Creator himself, who conducts them at different seasons in innumerable shoals to supply the world with nourishment.

By means of navigation Providence hath opened a communication between the most distant parts of the globe; the largest solid bodies are wafted with incredible swiftness upon one fluid by the impulse of another, and seas join the countries which they appear to divide.

The waters of the sea are not only prevented from destroying the earth, but by a wonderful machinery are rendered the means of preserving every living thing which moveth thereon. Partly ascending from the great deep through the strata of the earth, partly exhaled in vapour from the surface of the ocean into the air, and from thence falling in rain, especially on the tops and sides of mountains, where they break forth in fresh water springs, having left their salts behind them; they trickle through the valleys, receiving new supplies as they go; they become large rivers; and, after watering by their innumerable turnings and windings immense tracts of country, they return to the place from whence they came. The fertility of the earth is owing to God, "who watereth the hills from his chambers." Hence all the glory and beauty of the vegetable

world; hence the grass that nourisheth the cattle, that they may nourish the human race; hence the green herb for food and medicine; hence fields covered with corn for the support of life; hence wine and olive trees laden with fruits, whose juices exhilarate the heart, and brighten the countenance.

APPENDIX TO LECTURE XIV.

BY THE EDITOR.

CONTAINING A DESCRIPTION OF AN APPARATUS, USEFUL IN THE MAKING INFLAMMABLE, &c. AIRS, AND EXHIBITING THEIR CURIOUS EFFECTS. A DESCRIPTION OF THE NEW PHILOSOPHICAL, OR INFLAMMABLE AIR LAMP. METHOD OF ANALYZING MINERAL WATERS; A LIST OF FLUID TESTS, THEIR RE-AGENTS, AND FLUXES, NECESSARY THERETO, AND FOR EXAMINING MINERAL BODIES; AND A LIST OF CHEMICAL PREPARATIONS FOR PERFORMING MANY AMUSING AND INSTRUCTIVE EXPERIMENTS.

Our Author having planned every Lecture to such an extent, as to employ time sufficient for the reader to consider as one Lecture; and as a further description of some apparatus, and account of experiments, may add to the information of many young readers, I have thought it best to insert them here. They are of an entertaining nature, and, with beginners, will serve to illustrate much of the theory in an impressive manner.

INFLAMMABLE AIR APPARATUS.

For merely the production of inflammable, &c. airs, and the introducing them into glass jars, or other vessels, there is no article more convenient than the bottle with a bent neck, shewn at *a*, *plate* 6, *fig.* 1. But as such are very subject to be cracked or broken, and not sufficient to retain the air when made, I prefer, and recommend the bladders with brass stop-cocks and pipes, such as is represented at *plate* 7, *fig.* 5. By these, the airs may be kept for any length of time, and when desired, transferred or compounded in any manner, suitable to the purposes of the operator. The following description will give the reader an idea of what I think is the cheapest and readiest of any hitherto constructed: A, *plate* 7, *fig.* 9, represents a common stone or earthen jar, in which the materials for making the inflammable air are to be placed; some iron filings, or, what is best, clean iron turnings; oil of vitriol, and about three or four times that quantity of water, are the generally allowed proportions for producing the air; the vitriol to be put in last; a common stout wine bottle or glass decanter may also serve, when a great stock of air is not desired. B is a tin cylinder, or cistern, containing withinside a syphon. This is to be about two-thirds filled with water; by a cork fitted at its base, it is adapted to the neck of the bottle A. The air will thereby pass through the water in its passage upwards, purifying it in a proper manner, and which, for particular experiments, is indispensably necessary. To a socket in the upper part of the cylinder is fitted the stop-cock of the bladder C; the bladder must be soaked in water, and the common air excluded as much as possible, before it is applied to the vessel B. In less than a quarter of an hour the bladder will be inflated with

the air; the stop-cock piece, *a*, must then be turned, itself and the bladder taken off, and another bladder applied; and so any number of bladders may thus be filled as may be wanted.

A bladder may be filled with any other elastic fluid by connecting its stop-cock to the end of a long tube, luted to the neck of a retort, in which oxygene or vital, or other air may be making; or to the top of another glass receiver, immersed in water in the pneumatic tub, *plate* 6, *fig*. 1, already filled with the particular air. A small brass piece, *fig*. 10, with two female screws, is useful to connect the stop-cocks of two bladders together, when the admixture of two different airs together is desired, such as the oxygene and inflammable, &c.

The bladder, *fig*. 5, of the stop-cock and pipe, being pressed under the arm, and a lighted taper or piece of paper applied instantly to the orifice of the pipe, will inflame the air, and produce a burning lambent flame as long as any air remains, as our Author has observed at page 565. A brass pipe, with a moveable jet, *a*, *fig*. 11, with a fine perforation at its extremities, which are turned at right angles, being screwed on the stop-cock instead of the plain pipe, will produce a rotatory motion by the action of the air from the bladder, and when inflamed give a beautiful circle of fire in a darkened room, and of a degree of strength and brilliancy in proportion as the bladder is pressed. By constructing such sort of articles in more complicated and figurative ways, and with inflammable air, the late Mr. *Diller* exhibited in London, a few years ago, the most pleasing and splendid fire-works, that ever came under public observation, to which I was an eye-witness, and, as an instance of skill in the contrivance of machinery, I think the most singular. His figures were, a flower, a moving and varying sun, a changing star, a dragon pursuing a serpent, a star

of knighthood, a flame for light-houses equivalent to 100 *Argand's* lamps, with a great variety of others. The whole was without smell and smoke, and with a beautiful variety of colours. If the apparatus is yet in reserve, it is to be hoped that they may be again put into action for the entertainment of the public.

A capillary tube, or pipe with a fine bore, placed on the top of a glass bottle, or conical shaped jar, containing inflammable air, will serve in a simple way to exhibit a small lambent flame, and will burn till the air is nearly exhausted: it is difficult to be blown out; on which account it has been called the magic or philosophical candle.

It is a pleasing experiment by means of one of these bladders, filled with inflammable air, connected to a tobacco-pipe, to blow up from soap-suds in a bason small balloons; their levity will cause them to ascend, and a lighted candle or taper being applied, they will burst with an explosion. If oxygene or vital air is mixed with the inflammable, the explosion and concussion of the air is prodigiously great.

But the most curious article of this sort is the inflammable air lamp, already noticed at page 567, see *plate* 7, *fig*. 6. The contrivance of this sort of machine is owing to Mr. *Volta*, Dr. *Ingenhouz*, &c. and, with some small variation in the figure, is the manner in which we now make them. A, is a glass jar for containing the inflammable air; B, an open glass urn to contain water, and by the pressure of which, the air is forced out of the jar A, through the brass pipe *a*; C, is the stop-cock, so perforated, that the water may descend from B into A, and the air pass out through the pipe *a*. When the bar of the stop-cock is turned to an horizontal position, the communication between the two vessels is shut, and the air obstructed; when turned to a vertical one, the

contrary. The lower jar, A, may be filled with pure inflammable air, either by means of the pneumatic tub, *plate* 6, *fig*. 1, and its apparatus; or more readily by the bladder of air, *fig*. 5, two of which accompany the lamp, and which must be managed as follows. Take off the cover, D, from the lamp, and turn the stop-cock upwards, and pour as much clear water down, as will fill the vessel, A, up to the pipe *a*. Unscrew this pipe, and in its stead screw the small brass piece, *fig*. 12, quite firm; to this screw one of the stop-cocks and bladder, *fig*. 5. With the bladder under one of your arms, one hand to the cock at C, and the other to that of the bladder, at the same instant, open the apertures, and directly press the bladder; this will force out the air upon the water in A, which will be driven up the glass pipe through the tube, into B, with a bubbling noise. When you have thus charged the vessel, A, with air, or as much as you desire, you turn quickly both the stop-cocks again, so as to cut off any connection with the external or common air; particular care must be taken, that the common atmospheric air does not mix with the inflammable, for the reader must know, from what our Author has before related, that if a mixture of inflammable and common air are fired, the explosion will be great, and himself endangered by the bursting of the glass vessels.

The other part of the principle of this lamp, or the means by which the air is lighted, consists of an electrical apparatus, and is as follows.

The mahogany basis, E F, is of the form of a box, about twelve inches square and five inches deep, in which is placed an electrophorus, consisting of a resinous cake, *c*, and metallic plate *d*, which by an hinge at its back, not represented in the figure, admits of being pulled upwards and let down by the silken string *b*, that is connected with it, and

the stop-cock C. It is a well-known property of this cake, that when once it is excited, it contains its electric effect upon the metal plate for a great length of time. A metallic chain, G, communicates with a wire and ball *e*, passing through a glass tube below, in the box over the plate, and above with a fine wire passing through a glass tube; this upper wire is bent to about one-eighth part of an inch distance from the flame pipe. Now it is evident to the reader, if the electrophorus in the box below is previously excited, that, by simply turning the stop-cock at C, with his hand, the silken string, *b*, will raise the metallic plate, which will give an electric spark to the ball and wire above, that conveys it up instantly to the flame pipe, and inflames the air issuing out of the pipe, from the pressure of the water in its descent into the vessel A. The cock, C, being turned back, the flame ceases, and turned again, appears, and will serve to light a candle, match, &c. at any hour of the day or night. The number of times that an instantaneous light may be produced will be very great, and in proportion to the inflammable air in the vessel A. If the cock is not turned back, the flame will continue till the whole of the inflammable air is consumed. The light is just sufficient to read a large print by in the night, or see the hour by a watch. When the electrophorus cake is to be excited, the silken string, *b*, is unhooked from the plate, and the apparatus drawn out of its box; the metallic plate lifted quite upwards, while, with a silken or dry cat-skin rubber, you briskly rub the surface of the resinous cake. About twenty revolutions in rubbing will be sufficient, and convey electricity enough to the plate, or to give a spark to the knuckle of a finger about an inch distant. The strength of the spark is the criterion of the strong excitation of the cake. The silken string and small glass tubes, through which the wire, G, passes, should

always be completely dry, to make the passage of the electrical spark quite perfect.

The whole height of the apparatus is about twenty-two inches, but no specific dimentions are essential; the disposition of the parts, and their proper connection are their chief requisites. Dr. *Ingenhouz* for a long time had a small apparatus upon a similar principle, by which he occasionally obtained a light for domestic purposes, both when at home and on his travels.

Fig. 13 represents a portable and convenient apparatus, called a lamp furnace, by which a great many operations may be performed in solutions, digestions, and distillations, without requiring much space or room. A, is a brass or iron rod, about two feet in height, screwed to a solid strong foot; on this slides three metallic sockets, carrying wires and rings, for supporting glass retorts, B, matrasses, &c. and may by the screws be set to desired heights. C, is a glass ball with a neck, called a receiver; but common one-ounce or two-ounce phials are generally more useful; this is luted to the neck of the retort, and serves to receive the distilled matter. D, is a wooden stand with a moveable dish, to set to any height proper for supporting the receiver C. E, is an open *Argand*'s lamp, with a metal cylinder, by which means various and necessary degrees of heat are given to the materials in the retort above. In many cases the heat from this lamp is sufficient, but should a strong red heat be wanted, a kind of iron chafing dish, to hold charcoal, and made to move upwards and downwards between two iron rods for supports, had best be adopted. With such an apparatus as the above, most of the principal chemical operations can easily be performed.

The blow-pipe for the mouth, *fig.* 14, is a very useful article to the chemical student. It should have fitted to its smaller end three or four caps

with different small apertures, through which the air upon the flame of a wax candle or lamp is to be urged upon the mineral, or other specimen to be examined, and which in size ought not to exceed a pepper corn. This, with some small apparatus for experiments, &c. as first recommended by the late Mr. *Magellan*, are now made in complete sets under my inspection, and, to a person desirous of performing the experiments in the diminutive way, will be found very deserving of attention.

If to this small collection is added, a tobacco-pipe, as a crucible, in which a number of operations may be performed in a common fire, especially if urged with a pair of good double bellows; an earthen pot or iron ladle, as a sand bath; apothecaries phials or Florence flasks, as matrasses; chafing dish or small iron stoves, for many useful purposes; basons, pans, cups, saucers, &c. the whole will constitute a cheap and no mean philosophical and chemical apparatus, and, as Mr. *Nicholson* observes, by which great discoveries have been made, and may be probably increased.

THE METHOD OF ANALYZING MINERAL WATERS.

An excellent opportunity is afforded by the analyzing of mineral waters and mineral bodies to the young student, who is desirous of exemplifying most of the chemical principles described in the preceding Lectures. I shall now first give the method from Mr. *Wieglib*'s General System, as published by Mr. *W. Nicholson*, in his valuable Chemical Dictionary, 4to. 1795, and then a list of such tests, agents, re-agents, &c. as are necessary for the operator to be furnished with; and afterwards insert directions for the making of a few select experiments of a very entertaining nature, in regard to dyes, colours, sympathetic inks, &c.

The investigation of mineral waters consists: 1. In the examination of them by the senses. 2. In the examination of them by re-agents. 3. In the analysis properly so called.

The examination by the senses consists in observing the effect of the water as to appearance, smell, and taste.

The appearance of the water, the instant in which it is pumped out of the well, as well as after it has stood for some time, affords several indications, from which we are enabled to form a judgment concerning its contents. If the water is turbid at the well, the substances are suspended only, and not dissolved; but if the water is clear and transparent at the well, and some time intervenes before it becomes turbid, the contents are dissolved by means of fixed air.

The presence of this gas is likewise indicated by small bubbles that rise from the bottom of the well, and burst in the air while they are making their escape, though the water at the same time perhaps has not an acid taste. But the most evident proof of a spring containing fixed air, is the generation of bubbles on the water being shaken, and their bursting with more or less noise, while the air is making its escape.

The sediment deposited by the water in the well is likewise to be examined; if it be yellow, it indicates the presence of iron; if black, that of iron combined with sulphur; but chalybeate waters being seldom sulphurated, the latter occurs very rarely. As to the colour of the water itself, there are few instances where this can give any indication of its contents, as there are not many substances that colour it.

The odour of the water serves chiefly to discover the presence of sulphur in it; such waters as contain this substance, smell of liver of sulphur, or of rotten eggs.

The taste of a spring, provided it be perfectly ascertained by repeated trials, may afford some useful indications with respect to the contents. It may be made very sensible by tasting water, in which the various salts that are usually found in such waters are dissolved in various proportions. There is no certain dependence, however, to be placed in this mode of investigation; for, in many springs, the taste of Glauber's salt is disguised by that of the sea salt united with it. The water too is not only to be tasted at the spring, but after it has stood for some time. This precaution must be particularly observed, with respect to such waters as are impregnated with fixed air; for the other substances contained in them make no impression on the tongue, till the fixed air has made its escape; and it is for the same reason that these waters must be evaporated in part, and then tasted again.

Though the specific gravity of any water contributes but very little towards determining its contents, still it may not be entirely useless to know the specific weight of the water, the situation of the spring, and the kind of sediment deposited by it.

The examination of the water by means of re-agents shews what they contain, but not how much of each principle. In many instances this is as much as the inquiry demands; and it is always of use to direct the proceedings in the proper analysis.

It is absolutely necessary to make the experiment with water just taken up from the spring, and afterwards with such as has been exposed for some hours to the open air; and sometimes a third essay is to be made with a portion of the water that has been boiled and afterwards filtered. If the water contains but few saline particles, it must be evaporated; as even the most sensible re-agents, such as the solution of silver, and the salts formed by the union of the terra ponderosa with the nitrous and muriatic

acids do not in the least affect it, if the salts whose presence is to be discovered by them are diluted with too great a quantity of water. Now, it may happen that a water shall be impregnated with a considerable number of saline particles of different kinds, though some of them may be present in too small a quantity: for which reason the water must be examined a second time, after having been boiled down to three fourths.

The substances of which the presence is discoverable by re-agents, are:

Alkalis and earths combined with aerial acid. Paper stained with Brazil wood will discover the presence of these substances in the water: if the water contains the smallest portion of alkali, they will change its red hue into a colour partaking more or less of the violet. A still greater degree of sensibility is shewn, according to Mr. *Watt*'s experiments, by the tincture of the leaves of the brassica rubra, as well as by that of rose leaves.

Alkaline salts. The taste is sometimes sufficient to indicate their presence in mineral waters impregnated with aerial acid, after these waters have been exposed to the air for some time; but for the sake of producing absolute conviction, let a paper stained with turmeric be dipped in the water previously warmed; the colour of this is changed by alkaline salts only, and not by earths: now, if the colour of the paper is changed, and a quantity of sal ammoniac put into the water produces a smell of volatile alkali, the water certainly contains fixed alkali.

Absorbent earths. Water which does not change the colour of paper stained with Brazil wood or litmus, and which, after having been boiled, does not render lime water turbid, contains absorbent earth: if this earth be of a calcareous nature, it will be precipitated by the acid of sugar, provided the water be taken fresh from the pump; but not after it has

been boiled, unless indeed a particle or two of this earth should be dissolved in another acid; but in this case the sediment will not be nearly so considerable as in the other. The case is the same with respect to barytes, or terra ponderosa.

A mixture of alkaline salts and earth. The water having been examined in the above-mentioned method, for the purpose of discovering the alkaline salt in it, let part of this water be made warm; if it becomes turbid, there is certainly, exclusively of the alkali, an earth dissolved in it by means of fixed air; besides which, it is possible the alkali may hold another portion of earth suspended.

Neutral salts in general. The purest vinous spirit serves to discover their presence; but, for the sake of ascertaining that the substance precipitated by it is a salt perfectly neutralized, the water must be filtered, as soon as the substance has settled, and when the spirit is evaporated, the residuum must be tasted; the taste will be sufficient to direct the experimenter with respect to the choice of his re-agents.

Vitriolic salts in general. A few drops of the solution of terra ponderosa in the muriatic acid, will be sufficient to discover the smallest particle of any vitriolic salt; the acid of which will fall down combined with the terra ponderosa in the baro-selenite, or barytic vitriol.

Muriatic salts in general. Waters containing these salts, throw down from a solution of silver in nitrous acid a white precipitate (luna cornea) which is insoluble in nitrous acid.

A mixture of muriatic and vitriolic salts. First, let a solution of the terra ponderosa in nitrous acid be poured into the water till nothing more be precipitated from it; the precipitate being separated, let a solution of silver be poured into the filtered liquor, till it ceases to yield any precipitation. The former of these precipitates indicates the presence of vitrio-

lic, the second, that of muriatic salts; and the difference in the quantity of the sediments shews the different proportion of these substances in water.

Earthy salts. Alkali saturated with fixed air, precipitates the earth out of all earthy and metallic salts. But, to know whether this precipitate be of a metallic or merely of an earthy nature, the experiment must be made with the Prussian alkali. If this throws down no precipitate, the former sediment was mere earth.

Calcareous salts. A few grains of the acid of sugar will discover these salts, provided that the water containing them has been previously boiled; if a precipitate is formed, there is no doubt of their presence.

A mixture of calcareous earth and calcareous salts. In order to ascertain their presence, the water must be boiled; if during the boiling an earth is thrown down, which, after having been dissolved in the acetous acid, forms a precipitate with the acid of sugar, and if the water yields at the spring a still greater sediment with the acid of sugar, it contains, besides a calcareous salt, a portion of calcareous earth.

A mixture of calcareous earth with salts, in which another earth is contained. Let a small quantity of a solution of acid of sugar be poured into the water; if it contains calcareous earth, a precipitation will ensue. To the superincumbent water, after it has been decanted off from the earth and filtered, a solution of alkali saturated with fixed air must be added. If another precipitation ensues, there is, besides the calcareous earth, another earthy salt in the water. For the purpose of discovering it, a little diluted acid of vitriol must be poured upon the precipitate, which without causing any effervescence will form Epsom salt, if the precipitate be muriatic earth; regenerated heavy spar, if it be terra ponderosa; and alum, if it consists of earth of alum.

Muriated or aerated barytes. If the water be supposed to contain at the same time terra ponderosa combined with fixed air, and the same earth in a perfectly saline state, means must be used analogous to those that are employed for the discovery of calcareous earth; which is, to boil the water; to dissolve the earth which precipitates in the marine acid; and then try whether the vitriolic acid will produce a precipitate; if it does, the water contains terra ponderosa aerata. After this, let some vitriolic acid be mixed with distilled boiling water; when, if a precipitate is formed, it is owing to the muriatic salt of the terra ponderosa contained in the water.

Alum. The most simple means of discovering whether water of any kind contains alum, are, to boil the water in a very clean copper vessel, when, if it contains alum, it will exhibit a blue colour. When the quantity of alum in the water is small, the blue colour is not sensible; but it may be rendered very manifest by the addition of a little caustic volatile alkali. This method of discovering alum in water by means of copper, is founded on the property of this salt, in virtue of which it always exists with an excess of acid: it is this surplus of acid which acts upon the copper. A more certain method is to pour a solution of fixed alkali into the water, and to see whether the precipitate made by this means dissolves in water impregnated with fixed air: if it does, it is not earth of alum.

Metallic salts. Nothing is better adapted to the purpose of discovering the presence of metallic salts in waters, than the Prussian alkali purified by acids. If a solution of this alkali be poured into this water, after it has been exposed for some time to the air filtered, it makes a precipitate, which will be blue, if the water contains iron; brown, if it contains copper; and white, if it contains zinc. In case the Prussian alkali is not at hand, a solution of fixed

alkali may be used in its stead. This, with iron forms a yellow; with copper, a green; and with zinc, a white precipitate. This last precipitate becomes yellow, when exposed to the action of the fire.

Aerated iron. Water which contains aerated iron has its colour changed by an infusion of galls, but not by the Prussian alkali; however, after such water has been exposed for some time to the air, the iron is precipitated out of it, and it ceases to be affected by this infusion. If a water exclusively of this aerated iron contains an alkaline salt, the colour struck by the infusion of galls is rather red than violet.

Iron not much calcined and dissolved in mineral acids. Iron calcined to a certain point will dissolve in vitriolic acid; but if it has been too much, it is not soluble in this, although it be in the muriatic acid. If the iron contained in the water be in this latter state, the water will be made blue by the Prussian alkali, but will not be affected by an infusion of galls. In a water of this kind, let a piece of polished steel be steeped, and the water evaporated till it is reduced to one-half. Now, acids having more affinity with iron, while it retains its metallic state, than after it has been deprived of it, the iron in the former state will expel that in the latter, and at the same time partly reduce it; and thereby enable it to strike a black or deep purple colour with an infusion of galls.

Iron in two different states in the same water. A water of this kind deposits ochre, a short time after it is exposed to the air, and yields at the spring, with Prussian blue, a green or olive-coloured precipitate.

Cupreous salts. Water which contains these salts, acquires a distinct blue colour from a few drops of volatile alkali, and yields a brown precipitate by the addition of a little phlogisticated alkali.

Salts of zinc. Water that contains these salts affords, with Prussian blue, a white precipitate, which becomes yellow in the fire, and turns white again as soon as it is cold.

Arsenic. If this substance be contained in the water, it will be discovered by pouring a solution of volatile liver of sulphur into the water, from which it will be precipitated of a yellow colour. A solution of gold may likewise be used for this purpose. The water may likewise be boiled down, and the residuum be thrown upon live coals; if it smells of garlic the water contains arsenic.

Combination of acids with manganese. If, on a little of a solution of vegetable alkali being poured into water, a white precipitate is formed, and if the precipitate becomes black in the fire, and is soluble neither in the nitrous nor vitriolic acid, the water contains manganese.

Liver of sulphur. Nitrous acid destroys the odour of the waters which contain these substances, and separates the sulphur. On the other hand, the vitriolic and common marine acids augment the smell, while they separate the sulphur. But if it be requisite to render the sulphur visible, the experiment must be made with a considerable quantity of water, and the whole suffered to stand undisturbed for some time. The solutions of lead, silver, and quicksilver in nitrous acid, and the solution of corrosive sublimate, yield with a water of this kind a brown or else a black precepitate; which, when dried, will burn on a red-hot shovel with a blue flame and sulphureous smell.

Hepatic air. The pure vitriolic and the phlogisticated marine acids neither augment nor diminish the odour of the water that contains this air; they likewise neither render it turbid, nor do they precipitate the sulphur; this last is effected by the de-

phlogisticated nitrous and marine acids, though in a very small quantity only. At the same time too they deprive the water of its offensive odour. The solutions of quicksilver, lead, and silver, do not yield any precipitate, except there is a considerable quantity of this air employed; and what is more extraordinary, this precipitate does not burn with a flame. The solution of corrosive sublimate, and the nitrous solution of quicksilver made with heat, give with this kind of water a white precipitate. The calx of silver turns black in it, and deprives it of its offensive odour; it loses this smell likewise in a copper vessel, after remaining in it a minute or two.

In order to obtain a water saturated with sulphureous gas, Dr. *Hahneman* exposes to a white heat, for a few minutes only, a pounded mixture of equal parts of sulphur and unslacked or fresh slacked lime; and throwing half an ounce of this with five drachms of purified tartar into a bottle containing two pounds of pure luke-warm water, stops it quickly with a cork; and after shaking it for ten minutes, and allowing the grosser particles to settle, pours off the milky liquor into another bottle, and mixes it by agitation with three or four tea cups of thick cream, or half an ounce or two ounces of gum arabic, or half an ounce of gum tragacanth bruised. Calcareous hepar requires 1920 parts of cold, and 840 of warm water: calcareous tartar 800 of cold, and 500 of warm, for their solution.

For a warm bath, he takes fourteen ounces of calcareous hepar, and one pound of cream of tartar pounded, and stirs them up in the water of the bathing-tub; or, in 300 lb. of water made warm to 100 degrees, he agitates three quarters of a pound of hepar, made with pot-ash, and then stirs up with it very briskly a quarter of a pound of strong oil of vitriol.—Or he takes four parts of scales of iron

fused with three of sulphur, till it ceases to yield a blue flame; puts half a pound of this, mixed with five pounds of water, into a bottle holding eight or ten pounds: on this he pours a quarter of a pound of oil of vitriol, instantly stopping it with a bladder tied over, and pricked with a needle; sinks it to the bottom of a high bathing-tub, filled with warm water, and mixes the air as it comes out by agitation with the water.

Fixed air. Waters which contain fixed air change the colour of tincture of litmus to red, but this colour must be carefully distinguished from the reddish hue exhibited by this tincture, when diluted with a great quantity of water, from which it is very different. According to Professor *Bergman*'s method, lime water may likewise be used, a practice which however stands in need of some improvement. When water contains a certain but small quantity of fixed air, it does not change the colour of the infusion of litmus; and, in this case, the quantity must be ascertained by distilling the water in a pneumatic apparatus. The taste of the water indicates the presence of this substance, only when the water contains a certain quantity of it; for it is by no means to be inferred, when the water does not taste sour, that it contains no fixed air, as the contrary circumstance sometimes takes place. A water of this kind generates bubbles at the spring, which burst at its surface with some noise.

The analysis of mineral waters shews in the first place, how much of each of these substances is contained in the water; and it is performed by evaporating the water, by which means one substance is obtained from another, when each of them is weighed separate. Some mineral waters contain volatile particles, which make their escape during the evaporation of the water; others contain such substances

as are liable to be decomposed by evaporation, or may more or less prevent the developement of the other parts.

Lastly, all of them contained fixed substances that remain behind in a dry and concrete state, after the water is evaporated.

Separation of the volatile substances.

In water which contains hepatic air these substances occur. If nitrous acid be poured on a portion of this kind of water, the quantity of sulphur precipitated by it, gives the quantity of the hepatic air contained in the water; each cubic inch of the latter containing a quarter of a grain of sulphur.

Water separated with fixed air. Part of such water is to be evaporated in the method described a little farther on. From another portion of it, according to Professor *Bergman*, the air is to be expelled, and afterwards mixed with lime water for the purpose of ascertaining the quantity of it. If *Bergman*'s prescription be followed literally, the fixed air will be loaded with vapours of the water, which will pass with it through the mercury, be condensed on its surface, and afterwards absorb part of the air. It is better to pass the air immediately through lime water; for, in this case, one part precipitates along with the calcareous earth which it meets with in its passage, as does likewise the remainder, if the apparatus be shaken a little. This earth too must be carefully separated by filtration. Now, as the quantity of fixed air contained in calcareous earth, and its specific gravity, is very well known, it is very easy to make an accurate estimate of the quantity of fixed air that is contained in the water; for instance, if half a drachm of calcareous earth be obtained, the water contains $18\frac{3}{4}$ grains of fixed air, or $32\frac{89413}{100000}$ cubic inches; allowing, with *Kirwan*, a cubic inch of fixed air to weigh $\frac{57}{100}$ of a grain.

In default of the pneumatic apparatus, provided it be certain that the water does not contain any fixed alkali, it needs only to be mixed with four times its quantity of lime water, and then filtered.

If the water contains alkali, the experiment must be made twice, *viz.* first at the spring, and afterwards when the water has been boiled; the weight of the second sediment is then to be subtracted from that of the first, *viz.* of the aerated earth, and it will appear what allowance is to be made for the weight of the fixed air.

Analysis of the volatile alkaline substances. If a substance of this kind be suspected in the water, let part of it, after having been weighed, be put into a retort, and about one-third of it drawn off by distillation; a quantity of marine acid is then to be poured on the distilled portion, till the saturation is complete: the sal ammoniac thus obtained is then to be dried and weighed; the quantity of acid in the sal ammoniac being known, it is easy to estimate that of the volatile alkali in the water. *Wenzel's* estimate of the volatile alkali contained in sal ammoniac seems to be more exact than that of *Bergman.* If these waters contain particles that may be either easily decomposed, or alter the product of the analysis, they must be treated in the following method:

Separation of the substances that are decomposed during the evaporation of the water, and which prevent the separation of the other ingredients. These substances are, liver of sulphur and metallic salts. acid of sulphur which was disengaged during the evaporation, combines with the alkaline substances that may happen to be contained in the water, and changes their nature. In metallic salts the metal becomes calcined, separates from its acid, and enters into new combinations with the other ingredients of

the water. Hence the liver of sulphur, as well as the metallic salts, must be decomposed, and an estimate made of the quantity in which they are present in the water previous to undertaking the evaporation.

Water that contains liver of sulphur. For the purpose of analyzing a water that contains liver of sulphur, a quantity of nitrous acid must be poured into it sufficient to precipitate all the sulphur. The precipitate is then to be separated and weighed.

Water that contains metallic salts. Pour into this water a solution of Prussian alkali, previously purified by means of nitrous acid; as soon as the precipitation ceases, the water must be filtered, and the precipitate drained and weighed.

Separation of the fixed and unchangeable substances. The separation of the volatile bodies, and of such as may prevent the separation of the fixed and unchangeable substances, having been effected; let a certain quantity of the water be weighed, and, after being evaporated to dryness, weighed again. The evaporation is best performed in vessels of glass or china. It is true, that a gentle heat can only be used with such vessels, and that consequently the evaporation goes on but slowly in them. But this inconvenience is ballanced by the certainty the operator has no other matter united with it.

In whatever manner the evaporation is performed, the residuum consists of salts which are soluble in the purest spirit of wine, of such as are soluble in cold water, and of such substances as cannot be dissolved by either of these menstrua. The first thing therefore to be done, is to pour a quantity of rectified spirit of wine on the residuum, and let them digest together for the space of a few hours in a gentle heat. The liquor is then to be decanted into another vessel, in order that its contents may be further analyzed, and in the mean time the analysis of the remainder to be continued. With this view,

a quantity of cold water is to be poured on the residuum, which must stand in a gentle heat for the space of six or eight hours, and be shaken now and then. The water is then to be decanted off into another glass, and some fresh water added to the remainder; after standing one or two hours longer, the water in both glasses is to be mixed and filtered, and set apart for the purpose of examining its contents. These consist of salts perfectly neutralized, and vitriolic salts, exclusively of selenite.. That part of the residuum which is insoluble in water and spirit of wine, consists of different earths, of the selenite, and of the iron that has been dissolved in the fixed air of the water. The bodies which have been dissolved in both liquids, are now to be separated from each other, as must the substances that compose the undissolved residuum.

Separation of the substances dissolved in the spirit of wine. These may be either sedative salt, common salt, nitrous acid combined with an earth, arsenic, or extractive matter.

There are three methods of separating these substances.

First method.

For sedative salt. The vinous spirit is to be mixed with twice its quantity of distilled water, and part of this mixture evaporated; if this be suffered to crystallize, sedative salt is obtained, of all the salts that are soluble in spirit of wine the only one that is crystallizable.

Salts with a calcareous basis. If the re-agents indicate a calcareous salt in the water, the calcareous earth is to be separated by the acid of sugar saturated with alkali. The quantity of the precipitate thus obtained, gives the quantity of the calcareous salt contained in the water. The salt acquired by crystallization, whether it be nitre or digestive salt, shews with what acids the calcareous earth is com-

bined. In order to separate this salt more accurately, the liquor may be evaporated to dryness, and the soluble part of the residuum extracted with spirit of wine; consequently, the digestive salt and cubic nitre, being insoluble in the spirit, are left behind. After these are separated, the spirit must be diluted with distilled water, and the undissolved substances separated by the method mentioned below.

Salts, the basis of which is heavy earth, or barytes. If, in consequence of the analysis made with the re-agents, the presence of a salt of this kind is suspected in the water, let a solution of Glauber's salt, or vitriolated tartar, be poured into the water. After this, either the digestive salt, or the nitre, whichsoever it be that is formed by this decomposition, must be separated.

Salts, the basis of which is magnesian earth. If the water contains a portion of these salts, there must be added a quantity of fixed alkali to the liquor that is left after the preceding experiment. The consequence of this will be, that the magnesia will be precipitated; and from the crystals, either of digestive salt or nitre, which may be separated either by crystallization or precipitation with spirit of wine, it will appear with what acid the earth was united. If the weight of these last salts, or that of the precipitated earth, be known, the quantity of Epsom salt in the water may be easily estimated.

Arsenic. If there be any reason to suspect this substance in the water, to the above-mentioned liquor, before it is suffered to crystallize, a small quantity of volatile liver of sulphur may be added; the arsenic will speedily unite with the sulphur, and afterwards the digestive salt, or the nitre, whichsoever of these is present, may be separated from the liquor.

Extractive matter. Last of all, the extractive matter must be separated from the spirit of wine,

With this view, the liquor that remains after these various processes must be evaporated to dryness. Some particles of it however adhere to the crystallized salts, as do likewise some saline particles to the extractive matter.

Second method.

This method is founded on the observation that, except arsenic and sedative salt, all others, which spirit of wine is capable of holding in solution, contain an earth. The vinous spirit charged with those substances, being mixed with a sufficient quantity of water, and the arsenic and sedative salt being thus separated from it, let a solution of silver in nitrous acid be poured into it; the precipitate hereby obtained indicates the quantity of marine acid that was present in the water combined with the earth. The remainder of the liquid is then to be precipitated with the fixed alkali: a more precise analysis of the earth obtained, will shew the nature and quantity of the salts of which it made a component part.

If, besides these, there are in the water other salts, the earth of which is combined with nitrous acid, in this case the quantity of the earth obtained will not correspond with that of the marine acid, as indicated by the solution of silver. But as all salts, in which the marine acid is combined with an earth, contain nearly the same quantity of earth, nothing more is necessary to be done, than to subtract from the earth, obtained by the foregoing process, the quantity sufficient to saturate the marine acid in a liquid state, and the remainder will give the weight of the earth dissolved in the nitrous acid.

For the purpose of ascertaining the nature and quantity of the earth obtained, let the precipitate made by the fixed alkali be dissolved in nitrous acid, to which must be added, drop by drop, a small quantity of a solution of acid sugar, saturated with fixed alkali. In consequence of this, the calcareous earth

will be precipitated and combined with the acid of sugar, and the weight of the precipitate will point out the quantity of the calcareous earth contained in the liquor. Now, if after this liquor be separated from this precipitate by decantation, and a solution of alkali, saturated with fixed air, be poured into it, the muriatic and aluminous earth will be likewise precipitated. Lastly, let there be poured upon this mixture a quantity of distilled water, saturated with fixed air: the former of these earths will be dissolved, while the latter will be left undissolved.

Third method.

The arsenic and sedative salt being separated, let the remaining liquor be diluted with three times its quantity of water, and the earth precipitated from it with fixed alkali; the liquor being decanted off from the earthy precipitate, which must be analyzed in the method above-mentioned. Let there be poured into the former a small quantity of solution of silver. The weight of the precipitate, here produced, shews the quantity of marine acid that was combined with the earth.

Separation of the substances that are soluble in distilled water. These may be fixed alkali saturated with fixed air, all the perfect neutral salts, alum, Epsom salt, and other salts.

Fixed alkali. It is hardly possible to ascertain the quantity of mineral alkali that is contained in any water by the crystallization of this salt; for some part of it always mixes with the other salts, and it can never be obtained in a pure state. Let therefore any quantity of Epsom salt, but rather more than is sufficient, be taken to saturate the alkali in the water. The water will become turbid, and, in the space of five or six hours, let fall a quantity of muriatic earth. But the redundant quantity also of the Glauber's salt that may exist in the water, as well as that of the Epsom salt employed in this process, must be

taken into consideration. These are the only means on which any dependance can be placed in analyzing alkaline waters.

Alum and Epsom salt. If these are found together in the water, either with or without any other salt, the best mode of ascertaining the quantity of them, is to decompose them; thus let a solution of fixed alkali be added, drop by drop, to the water, till it ceases to render the water turbid. The precipitate being washed, dried, and weighed, a quantity of distilled water, saturated with fixed air, must be poured upon it, which will dissolve the magnesian, but not the aluminous earth; the weight of the latter, subtracted from the whole of the precipitate, will give the weight of both earths. The analysis is to be continued, and the vitriolated tartar, formed by the decomposition, must be separated. This may be easily done by crystallization.

If the Epsom salt be mixed with Glauber's salt, it is almost impossible to separate them by crystallization, as both of them crystallize at the same time. Here, as before, recourse must be had to the decomposition of them. The portion of Glauber's salt contained in the water may be determined by the weight of the precipitated earth; the same holds good with respect to alum, when mixed with other salts.

Glauber's salt, common salt, and nitre. 1. A solution of terra ponderosa in nitrous acid is to be poured into water that has stood some time on the residuum of the evaporated water, and the precipitate dried and weighed. By this means, the quantity of Glauber's salt contained in the water will be ascertained.

2. Into this water that has been separated from the above-mentioned precipitate by filtration, let a quantity of solution of silver in nitrous acid be poured; this will cause a precipitate, which must be separated

from the supernatant liquid, and, when dry, weighed for the purpose of discovering the quantity of common salt contained in the water.

3. If the weight of the Glauber's salt and common salt, taken together, be still not equal to that part of the residuum that has been dissolved in cold distilled water, this circumstance gives room to suspect, that there is nitre in it, the quantity of which is discoverable by the difference of the others.

Separation of the substances contained in that part of the residuum of the water, which is not soluble either in spirit of wine, or in cold water, viz. *selenite, iron, siliceous, aluminous, magnesian, calcareous, and ponderous earth.* I. Selenite. The residuum, after being weighed, is to be boiled with five hundred times its weight of distilled water; the selenite will be dissolved, and will pass through the filter with the water, while the iron and the earth will remain behind. The remainder must now be dried upon the filter, and weighed; if the weight be subtracted from its former weight before it was boiled, it will give that of the selenite.

In order to separate the selenite, marine acid may likewise be poured upon the residuum; the acid will dissolve the iron and the earths, and the selenite will remain behind, together with a little siliceous matter. For the purpose of ascertaining the quantity of the latter, nothing more is necessary than to wash the residuum with distilled water; what remains after this is siliceous earth, the quantity of which is easily determined.

II. Siliceous earth. The selenite being separated in the former of these methods, upon what remains on the filter, after it has been dried and weighed, pour a quantity of marine acid, when it will all dissolve except the siliceous earth, and the deficiency in the weight will determine the quantity of this earth.

III. Iron. Into this solution let there be poured a little Prussian alkali, purified by means of marine acid, the iron will be precipitated in the form of Prussian blue.

The Prussian alkali must be previously purified by acids, in order to prevent the precipitation of the earthy salts, and to make the precipitate charge itself more perfectly with the colouring matter. In Professor *Bergman*'s method, the siliceous earth combines with the alkali, and in this case it is very difficult to ascertain the quantity of it.

IV. Calcareous earth. After the separation of the iron by means of the Prussian alkali, the liquor is still charged with different kinds of earths. In order to separate the calcareous earth from this liquor, a solution of acid of sugar saturated with alkali must be added, drop by drop, when the calcareous earth will be precipitated in the form of a calx saccharata, or calcareous saccharine salt.

V. Magnesian and aluminous earths. In order to obtain these earths from the liquor standing upon the calcareous saccharine salt, a solution of fixed alkali is to be added to it, till the precipitation ceases; the precipitate, which consists either of earth of alum, or magnesian earth, or both together, is then to be washed, dried, weighed, and put into a large bottle that is perfectly air-tight, and the bottle is to be filled with distilled water, perfectly saturated with fixed air; this will dissolve the magnesian earth, and leaves the aluminous earth behind.

LIST OF FLUID TESTS, RE-AGENTS, AND FLUXES.

The following is a list of fluid tests, re-agents, and fluxes for the blow-pipe, necessary for the analyzing of mineral waters, the examination of mineral bodies, &c. &c. The numbers correspond to those on the labels pasted on the well-stopped phials, and which

are usually packed into a mahogany portable chest with two drawers, and, excepting some additions, are according to an useful descriptive tract lately published, entitled, A Description of a Portable Chest of Chemistry; or, A Complete Collection of Chemical Tests for the Use of Chemists, Physicians, Mineralogists, Metallurgists, Scientific Artists, Manufacturers, Farmers, &c. by *J. F. A. Gottling*, of Jena, in Saxony, translated from the German, 1791, 12mo. This book describes more than 150 experiments, and which the young practitioner should consult at the time of commencing his operations.

First Drawer.

1. Tincture of litmus.
2. Lixivium of Prussian blue.
3. Vitriolic acid.
4. Nitrous acid.
5. Marine acid.
6. Acetous acid.
7. Mild volatile alkali.
8. Mild vegetable alkali.
9. Highly rectified spirit of wine.
10. Lime water.
11. Distilled water.
12. Calcareous liver of sulphur.
13. Crystals of tartar in powder.
14. A phial containing a wine test, for detecting bad wines.
15. Vitriolated argilla (alum).
16. Oil of olives.
17. Oil of linseed.
18. Oil of turpentine.
19. Ether.
20. Acid of sugar.
21. Solution of alum.
22. Oil of tartar per deliquium.
23. Salt of tartar.

24. Aqua regia for gold, two nitre and one marine.
25. Aqua regia for platina, half marine and half nitrous acid.

The three following are the most esteemed fluxes, to be used with the blow-pipe.

26. Dry mineral alkali.
27. Glass of borax.
28. Glacial acid of phosphorus.
29. Nitre powdered.
30. Red tartar powdered.
31. White arsenic.
32. Vitriol of iron, and copper.

Second Drawer.

1. Caustic vegetable alkali.
2. Caustic volatile alkali.
3. A solution of lead in acetous acid.
4. A solution of soap.
5. A solution of arsenic.
6. A solution of corrosive sublimate in distilled water.
7. A solution of mercury in nitrous acid, prepared with heat.
8. A solution of mercury in nitrous acid, prepared without heat.
9. Volatile liver of sulphur.
10. Spirituous tincture of galls.
11. Ponderous earth dissolved in marine acid.
12. Nitrous solution of silver.
13. Nitrous solution of copper.
14. Purified sal ammoniac.
15. Purified Epsom salt.
16. A solution of vitriol in copper.
17. Cuprum ammoniacum.
18. Quicksilver.
19. Mineral alkali.
20. Calcined borax.

21. Fusible salt of urine.
22. Essential salt of wild sorrel.
23. Salited lime.
24. Sugar of lead.
25. Tincture of turmeric.
26. Tincture of Brazil wood.

To the preceding are added prepared papers, *viz.*

1. Litmus paper.
2. Brazil wood paper.
3. Turmeric paper.
4. Litmus paper reddened with vinegar.

And occasionally are packed with the same apparatus two cylindrical glass cups, to exhibit the operations by; two or three small glass matrasses, to contain the substances with their solvents over the fire; a small glass funnel; a small porcelane pestle and mortar; one or two small crucibles; a wooden trough to wash the ground ores; some sticks of glass, and other small articles convenient in the processes.

The above constitute what has been called the *Humid Laboratory*. A blow-pipe with fluxes, silver spoon, and other useful mineralogical implements, are packed into a pocket fish-skin case, and are called the *Dry Laboratory*.

The whole of the preceding tests, or any select quantity, prepared in a genuine manner by an eminent chemist, with *Gottling*'s descriptions, are sold at our shop in Holborn.

For the method of examining mineral waters and mineral bodies by analysis, I refer the reader to *Bergman*'s Chemical Essays, *Kirwan*'s Elements of Mineralogy, 2 vols. 8vo. 1798, and other eminent writers upon the subject.

The following articles have been selected chiefly for the entertainment of young students, and are the preparations as first made by the ingenious chemist, Mr. *Willis*.

A LIST

OF

CHEMICAL PREPARATIONS

FOR PERFORMING MANY AMUSING AND INTERESTING EXPERIMENTS.

No. I. Acid of vitriol.
II. Fixed alkali dissolved.
*II. Dry fixed alkali.
III. Volatile alkali.
IV. Syrup of violets.
V. Copper in acid of vitriol.
VI. Epsom salts in water.
VII. Tincture of galls.
VIII. Iron in acid of vitriol.
IX. Silver in acid of nitre.
X. Quicksilver in acid of nitre.
XI. Lead in acid of nitre.
XII. Copper in acid of nitre.
XIII. Invisible ink.
XIV. Marking ink.
XV. Washing ink.
XVI. Green ink.
XVII. Phlogisticated alkali.
XVIII. Phosphoric ether.
XIX. Solution for firing tin.
XX. Solid phosphorus.
XXI. Sal ammoniac.
XXII. Spirit of wine.
XXIII. Solution of soap.
XXIV. Blue liquid dye.
XXV. Liquor of flints.

DIRECTIONS FOR MAKING THE EXPERIMENTS.

Experiment 1. To three or four tea-spoonfuls of the fixed alkali, No. II. in a wine glass, add by little at a time some of No. I. a violent ebullition will arise; the fixed air escaping, particles of salt will be forced up with it and resemble a fountain: keep adding by degrees of No. I. till no more ebullition is excited, and great part of the liquid will be converted into a salt.

Experiment 2. Two or three tea-spoonfuls of No. III. put into a wine glass will smell very pungent; if you add to it by degrees No. I. and stir it with a small stick, the smell will entirely be taken away; and by adding some of No. II. to the mixture, it will become pungent again.

Experiments 3 *and* 4. Put half a table-spoonful of No. IV. and three table-spoonfuls of water into a glass, and stir them well together with a stick, and put half of the mixture into another glass. If you add a few drops of No. I. into one of the glasses and stir it, it will be changed into a crimson; and a few drops of No. II. into the other glass, it will change it green, upon stirring it.

If you drop slowly into the green colour from the side of the glass a few drops of No. I. you will perceive crimson at the bottom, purple in the middle, and green on the upper surface; and by adding a little of No. II. to the other glass, the same colours will appear in different order.

Experiments 5 *and* 6. If you put a tea-spoonful of No. V. into a glass, and add two or three table-spoonfuls of water to it, there will be no sensible colour produced; but if you add a little of No. III. to it, and stir it, you will perceive a very beautiful blue colour: upon adding a little of No. I. the co-

lour will instantly disappear upon stirring it; and by adding a little of No. II. will return again.

Experiments 7 *and* 8. Put a tea-spoonful of No. VI. into half a glass of water, and stir it; add gradually a little of No. II. and a white precipitate will fall down, which is magnesia; then add gradually of No. I. and stir it, and the liquor will become transparent.

Experiments 9 *and* 10. Put a tea-spoonful of No. VII. into half a glass of water, and drop into it a little of No. VIII. and a black colour will be produced; add a little of No. I. and the colour will be destroyed, and by adding some of No. II. be restored again. In all these experiments, stirring with a stick or piece of a match is necessary.

Experiment 11. Put three or four tea-spoonfuls of No. VI. into a glass, and add gradually of No. II. and stir it; a white solid body will be produced from the two liquids; this solid body may be converted again into a liquid by adding copiously of No. I.

Experiment 12. Mix equal parts of No. VI. and No. XXII. together and stir them well, let the mixture stand for a minute or two, and a solid body of crystallized salt will be produced. In the winter, the solid salt is produced instantly by shaking them together; but to make it act instantaneously, the solution No. VI. should be fresh made.

Experiment 13. Put half a tea-spoonful of No. VIII. into half a glass of water; by adding a few drops of No. XVII. a Prussian blue will be precipitated.

Experiment 14, Is made with the phosphoric ether, No. XVIII. to be used according to the following directions. Wet a lump of sugar about the size of a large nutmeg, and put it into a bowl or bason of water, stirring it about a little with your finger; when there will instantly appear a pleasing illumination, which, by blowing on it, will cause curious variations. The water should now be quite cold.

Experiment 15, Is made with the solid phosphorus, No. XX. to produce beautiful fire-works in miniature, thus: Put half a drachm of the phosphorus into a large pint Florence flask, holding it slanting that the phosphorus may not break the glass; pour upon it a gill and an half of water, and place the whole over a tea-kettle lamp, or any common tin lamp, filled with spirit of wine; light the wick, which should be almost half an inch from the flask; as soon as the water is heated, streams of fire will issue from the water by starts, resembling sky-rockets; some particles will adhere to the sides of the glass and represent stars, and will frequently display brilliant rays. And these appearances will continue at times till the water begins to simmer, when immediately a curious aurora borealis begins, and gradually ascends till it collects to a pointed flame; when it has continued about half a minute, blow out the flame of the lamp, and the apex that was formed will rush down, forming beautiful illumined clouds of fire rolling over each other for some time, which disappearing, a splendid hemisphere of stars presents itself: after waiting a minute or two, light the lamp again, and nearly the same phenomena will be displayed as from the beginning. Let a repetition of lighting and blowing out the lamp be made for three or four times at least, that the stars may be increased; after the third or fourth time of blowing out the lamp, in a few minutes after the internal surface of the flask is dry, many of the stars will shoot with great splendor from side to side, and some of them will fire off with brilliant rays; and these appearances will continue several minutes. What remains in the flask will serve for the same experiment several times, and without adding any more water. Care should be taken, after the operation is over, to lay the flask and water in a cool secure place.

In using the solid phosphorus, let a cup of water be always near you; and, when you write any thing with it upon a wall, &c. do not keep it more than half a minute at a time in your hand, for fear the warmth of your hand should set it on fire: when you have wrote a few words with it, put the phosphorus into the cup of water, and let it stay a little to cool; you may then take it out and write with it again.

A stick of phosphorus put into a large dry phial not corked, will exhibit a light in the dark sufficient to discern any thing in a room when held near it. This has lately been asserted to be similar to the sepulchral lamps of the ancients; but the phenomena of their perpetual light may be explained upon a more rational principle. The phial should be kept in a cool place, where there is no great draft of air, and it will continue its luminous appearance for more than twelve months.

Experiment 16, Is with the solution for firing tin, No. XIX. by this experiment the phlogiston is partly transferred to the copper, and part of it deflagrates. The directions are as follow: half a tea-spoonful of the solution being poured on the middle of a piece of tin foil; the foil must then be instantly folded over it on every side and pressed close: it will then take fire. The fumes being pernicious, had best be avoided as much as possible: it is best to perform the experiment under the chimney throat. The salt will have the same effect, but more slow; which, when used, must be put on the tin with a little spittle, folded, and pressed close as before; the dry salt having no effect without moisture.

Experiment 17. If you mix about a tea-spoonful of each of the numbers XXI. and *II, and put it into a phial, you will produce a smelling salt; and if you add a few drops of water, and shake the whole in a phial, it will be very pungent.

THE FOLLOWING EXPERIMENTS ARE BY SYMPATHETIC INKS.

Write with a new pen with No. XIII. any words you please and let them dry, and they will be perfectly invisible; then write any other words or name over it with No. XIV. observing to shake it well before you write with it, and it will seem as if written with common ink; when that is perfectly dry, pour a little of No. XV. on some tow, and with it wash off what was written with No. XIV. and what was written with No. XIII. will appear black.

Green ink. If you draw a tree on paper with bare branches, with a black lead pencil, and with an hair pencil, or pen, form leaves on the branches with this ink; when it is perfectly dry, the leaves will not be discernible; but, upon warming the paper before the fire, the leaves will all appear of a beautiful green, as in summer; in about ten minutes they will disappear again, and represent winter; and by warming the paper again, the leaves will re-appear. This may be repeated several times at your pleasure.

Observe not to put the paper before a fierce fire, lest you scorch it; and let it continue no longer before the fire, than till the leaves appear plain.

A BRIEF ANALYSIS OF WATERS BY PRECIPITANTS.

The clearness of water equal to that of crystal is a sign of tolerable pure water; on the contrary, a turbidness shews plainly that heterogeneous matters are so grossly mixed with it, as to obstruct the passage of the rays of light.

When the bottom is clay or mud, the water is never perfectly clear; but when it runs over sand, it is in general very transparent.

Good water is entirely without colour; but all colourless waters are not to be considered as good.

A brown colour, verging to red or yellow, is found in dull stagnant waters; it is sometimes occasioned by iron, sometimes by putrid extractive matters, and sometimes perhaps is derived from some unctuous substance. A blue colour indicates a solution of copper; a green one, that of iron.

If, upon agitation, water emits a number of airy bubbles, a quantity of aerial acid is inherent.

Good water has no smell; such as abounds in aerial acid, diffuses a penetrating odour. Such as contains any hepar sulphur, yields a smell resembling that of putrid eggs, as Harrowgate water.

Stagnant waters have a putrid offensive smell. A nice taste will distinguish the difference of several waters.

Aerial acid occasions a gentle pungent acescent taste; a bitterness accompanies those waters which contain Glauber's salt, nitre, or magnesia; a slight austerity proceeds from lime and gypsum; a sweet astringency from alum; a saltishness from common salt; a lixivious flavour from alkali; a bitter astringency from copper; and an inky taste from iron.

Syrup of violets has been a very universal test for waters containing acid and alkali, by their being changed either green or red, as in Experiments III. and IV. This in general answers, except in chalybeate and aluminous waters.

Tincture of galls, No. VII. shews iron in water by changing it purple or black, as in Experiments IX. and X.

If water contains any copper, it will be converted blue by dropping in a little of No. III. as is shewn in Experiments V. and VI.

Phlogisticated alkali, No. XVII. precipitates from water containing iron a Prussian blue, as in Experi-

ment XIII. If water contains any copper, this alkali precipitates a reddish brown colour.

The fixed alkali, No. II. precipitates magnesia from waters containing it, as in Experiments VII. and VIII.

A solution of soap separates all earthy matters, such as gypsum, lime, and magnesia, which are principally dissolved in hard water.

A solution of silver in the acid of nitre, by a single drop discovers whether there is any common salt in water by producing white striæ.

A solution of mercury in acid of nitre gives different precipitates.

If waters are impregnated with caustic vegetable alkali, a yellowish white; if with mineral alkali, yellow, which soon grows white; if with volatile alkali, a greyish colour; with marine acid, common salt, and all other substances containing that acid, a white precipitate.

Lime water dropped into any water containing the aerial acid, is by means of the fixed air converted into chalk.

ELECTIVE ATTRACTIONS.

By elective attraction is understood, the power by which the constituent parts of bodies unite; but, as the cause of the power is unknown to us, we must consider it only as a power of combination.

It may be a simple affinity or attraction, as is exemplified in mixing water with water, oil with oil, &c. or it may be compound, by mixing heterogeneous bodies together.

All bodies consisting of two or more constituent parts, may be said to be compounded by attraction; thus sea water contains not only common salt, but magnesia, and other substances; and even common salt contains the marine acid and mineral alkali.

Though many bodies do unite by attraction, yet there are other bodies that have a stronger attraction to one of the united bodies, than that which has been mixed with it. For, if I pour strong acid of vitriol on common salt, the marine acid will be expelled, and the mineral alkali being united with the vitriolic acid, will form Glauber's salt.

So Epsom salt readily dissolves in water which attracts it; but upon effusion of spirit of wine, the water having a stronger attraction to spirit of wine, quits the salt, which readily crystallizes at the bottom, as is exemplified in experiment XII. but in this case the solution must be more diluted.

Again, fixed alkaline salt, No. *II. has a stronger attraction to water; for, if you add spirit of wine to the dry fixed alkaline salt, the watery particles will be extracted from the spirit of wine, and the salt will be dissolved after shaking them.

If to one ounce of sugar of lead is added a pound of water, the curious zinc tree, as it is called, may be produced by means of this solution. A pint glass decanter is to be filled with the solution; a circular-shaped brass ring suspended from the stopper, and to the upper extremity of this a lump or small bullet of zinc is to be fastened. The preparations being left for one evening, a very curious precipitation on the wire will take place, from the strong affinity that the zinc has to the acid.

There are various tables of affinities of bodies or elective attractions published, for improving students in chemistry, and are found of great utility.

I have here added a small abridged table of affinities, to give some idea of the use of them.

TABLE.

Water.	Fixed Alkali.	Volatile Alkali.	Acid of Nitre.	Acid of Vitriol.
Fixed Alkali.	Acid of Vitriol.	Acid of Vitriol.	Fixed Alkali.	Fixed Alkali.
Spirit of Wine.	Acid of Nitre.	Acid of Nitre.	Volatile Alkali.	Volatile Alkali.
	Acid of Salt.	Acid of Salt.	Absorbent Earths.	Absorbent Earths.
	Acetous Acid.	Acetous Acid.	Iron.	Zinc.
	Sulphur.	Sulphur.	Copper.	Iron.
			Lead.	Copper.
			Mercury.	Silver.
Water.			Silver.	Tin.
Spirit of Wine.				Lead.
Epsom Salt.				Mercury.

EXPLANATION.

The two columns of water have already been explained; I shall now exemplify the column of the acid of nitre. Every one of the intermediate bodies between silver and the acid of nitre will precipitate the silver: but to proceed progressively. If to the solution of silver in the acid of nitre a little quick-

silver or mercury is added, the quicksilver will be dissolved, and the silver will fall down and form a resemblance of a tree called Arbor Dianæ, whose branches have the splendor of silver. The liquor will then be a solution of mercury; if you put a thin piece of lead into this last solution, the mercury will be precipitated in form of a calx or powder, and the liquor will be a solution of lead. If to this you add a thin slip of copper, the lead will fall down and the copper be dissolved: if to this solution of copper you put in a clean iron nail, the iron will be dissolved, and the copper in precipitating will receive phlogiston, or the inflammable principle from the iron, and incrustate the nail with pure copper, as far as the liquor reaches. Absorbent earths and volatile alkali will precipitate the iron, and fixed alkali either of the other precipitants. The last solution will be only salt-petre or nitre dissolved in water.

The experiment of the Arbor Dianæ may be exhibited in a beautiful way from the following directions:

On a slip of glass, two inches long and one wide, lay a small quantity of the above solution of silver; then lay a small piece of brass or copper in the lower part, and you will see it vegetate into a beautiful sort of shrub immediately; then with a pencil draw a fluid stroke from the shrub, to the lower part of the glass, and it will form the body of the tree; and at the bottom a stroke may be drawn for the ground; then, shaking a few brass filings over the body of the ground, it will complete the tree. If to the slip of glass is put on another of brass, and held in a coal fire till it becomes red-hot, the silver tree will appear to be converted into a gold one. Under a glass magnifier, or microscope, the silver vegetation appears in a still more beautiful manner.

If the fixed alkali be added to any of the solutions below it in the column, the substances dissolved will

be readily precipitated, and the liquor become salt-petre dissolved.

To effect many of these changes you must allow a day or two, as some of the metallic bodies dissolve slowly, and the more so without heat.

To procure copper from waters impregnated with it, they put in a quantity of old iron, and the copper will be precipitated in its own form, and requires only to be melted, as it receives phlogiston from the iron which loses it whilst it is dissolving.

You may easily conceive this, by putting the point of a knife into a little of No. V. in a glass, in a minute or two the part in contact with the liquor will be covered with a thin coat of copper; which is accounted for in the column of acid of vitriol, that acid having a stronger attraction to iron than copper.

AN ENTERTAINING METHOD OF DYEING RIBBONS.

Into a small bason with a little water in it, drop some of the blue liquid dye, No. XXIV. and put any white ribbon into the mixture, and let it be well soaked for a minute or two, then press the liquor from it and wash the ribbon, and it will be of a blue colour; you may make it of any shade you like by adding more or less of No. XXIV.

If to the same liquor you dip in a yellow ribbon, it will be dyed of a fine green; and if you immerge a red ribbon, a fine purple colour will be produced.

The phial to be shook well before any liquid is poured out.

You must be careful not to let any of the preparations fall on your cloaths, as many of them will stain and injure them. To remove the stain on your fingers, wash them in water mixed with a little slacked lime.

LECTURE XV.

ON OPTICS.

THE advances made in the knowledge of optics in the last and present age, are such as do honour to human nature and philosophy. The theory of light and colours by Sir *Isaac Newton*, is a piece so excellent for invention, for judgment in conducting experiments, and for drawing the proper conclusions from them, that had it been *Newton*'s single work, it would not only have done honour to him, but to the country that gave him birth.* Of the faculties called the five senses, sight is without doubt the most noble; the rays which minister to this sense, and of which without it we could never have had the least conception, are the most wonderful and astonishing part of the inanimate creation.

Of this you will be satisfied when you consider their extreme minuteness; their inconceivable velocity; the regular variety of colours which they exhibit; the invariable laws according to which they are acted upon by other bodies, in their reflexions and refractions, without the least change of their original properties; and the facility with which they pervade bodies of great density, and of the closest texture, without resistance, without disturbing one another, without giving the least sensible impulse to the lightest bodies.

Heat and light may be considered as the children of fire, as kindred qualities produced by the same cause, sometimes exerting their powers separately, sometimes united. We are, however, very ignorant

* Sir *J. Pringle*'s Discourses, p. 233.

of the intimate combinations of light and its mode of acting upon different bodies. Experiments upon vegetables give us reason to believe, that light combines with certain parts thereof, and that the green of their leaves, and the various colours of their flowers, are chiefly owing to this combination: for plants, which grow in darkness, are perfectly white, languid, and unhealthy: to make them recover vigour, and acquire their natural colours, the direct influence of light is necessary. Somewhat similar takes place even upon animals, and mankind degenerate to a certain degree, when confined too closely, or employed in sedentary manufactures. Though the sun is many millions of leagues from you, yet you see it as evidently, and feel its influence as powerfully, as if it were within your reach: it is within your existence. It supplies comfort and life to your animal body and life; and you could not survive an hour without its influence and operations.

Light is diffused on every side from its fountain, the sun: joined with air, it gives beauty and fruitfulness to the earth, supports vegetable and animal life, and the various kinds of motions throughout the system of nature. By their manifold and beneficial operations, as well as by the beauty and magnificence they produce, they point us to HIM who, in scripture, is called the GLORY OF GOD, by whom all things were made and upholden. The sun shines forth by day, the moon and stars by night; though they are not endowed like man with the faculty of speech, yet they address themselves to the mind of the intelligent beholder in another way, by the way of picture and representation.

Light introduces all nature to us, the trees, the flowers, the crystal streams, and azure sky: the fixed parts of nature are eternally entombed beneath the light; and we see nothing in fact but a creation of colours; nothing is an object of vision but light;

that which we call body or substance, that which reflects the various colours of light, lies hid beneath the appearance, is wrapt in impenetrable obscurity. Matter, at first sight, seems to be the only being we have correspondence with, to meet us every where; but when we examine, it shrinks like a phantom behind perception; we know it not; the closer we investigate its nature, the more it glides away from us, and all that we can at length ascertain, only points it out as a shadowy shrowd, under which SOVEREIGN POWER retires from plain view, and acts by regular laws.

The eye is the instrument by which we perceive the effects of light; its structure, its appurtenances, the various contrivances for performing all its internal and external motions, clearly point it out to be the work of Divine Wisdom; and he must be very ignorant of what has been discovered concerning it, or of a very strange cast of understanding, who can seriously doubt, whether or not the rays of light, and the eye, were made for one another with consummate wisdom and perfect skill in optics.

If you were to suppose an order of beings endued with every human faculty but that of sight, how incredible would it appear to such beings, accustomed only to the slow information of touch, that by the addition of an organ, consisting of a ball and socket of an inch diameter, they might be enabled in an instant of time, without changing their place, to view the disposition of a whole army, or the order of a battle, the figure of a manificent palace, or all the variety of a landscape? If a man were, by feeling, to find out the figure of the peak of Teneriffe, or even of St. Peter's church at Rome, it would be the work of a life-time.

It would appear still more incredible to such beings as we have supposed, if they were informed of the discoveries that may be made by this little organ

in things far beyond the reach of any other sense; that by means of it we can find our way upon the pathless ocean; that we can traverse the globe, determine its figure, its dimensions, and delineate every region; that we can measure the planetary orbs, and count the number of the heavenly host.

Would it not appear still more astonishing to such beings, if they should be farther informed, that by means of this same organ we can perceive the tempers and dispositions, the affections and passions of our fellow-creatures, even when they want most to conceal them? That by this organ we can often perceive what is straight and crooked in the mind as well as the body; that it participates of every mental emotion, the softest and most tender, as well as the most violent and tumultuous; that it exhibits these emotions with force, and infuses into the soul of the spectator the fire and agitation of that mind in which they originate? To many mysterious things must a blind man give credit. If he will believe the relations of those that see, his faith must exceed that which the poor sceptic derides as impossible, or condemns as absurd.* It is not, therefore, without reason, that the faculty of seeing is looked upon as more noble than the other senses, as having something in it superior to sensation, as the sense of the understanding, the language of intelligence.

The evidence of reason is called seeing, not feeling, smelling, tasting; nay, we express the divine knowledge by seeing, as that kind of knowledge which is most perfect in ourselves.

In the preceding Lectures on Fire you have seen how every thing subsists, and is preserved in the midst of an element capable of destroying and consuming all things; and yet, by its spontaneous action, it never destroys any thing. I have now to

* *Reid's* Inquiry into the Human Mind, p. 152, 155.

treat of another agent; light is a property of fire; by its operation it makes us pass in the twinkling of an eye from a state of the thickest darkness to that of the brightest day; it gives us as it were a new existence, making us go out of ourselves, and enter into communion and commerce with the most distant objects. Heat and light are undoubtedly the offspring of fire; but we are unequally unable to draw the line of separation, or to trace the bond that unites them. You need not be surprized at these various modifications of the same fluid, when you reflect on what you have already seen in this world, where beauty is so diversified, where being is so multiform, and yet where one and the same face of things is ever presented to your view.

As the eye among the organs of body, so optics among the branches of natural philosophy, is the most noble, curious, and useful; and this whether it is treating of simple vision, of that through glasses, or of the effects of mirrors, all still relates to the eye, and you are intimately concerned in all the phenomena of which it treats. If you cast your eyes on a large plain, and run rapidly over all the objects thereon, in an instant their image is exactly painted at the bottom of your eye; if you look through a telescope at a distant object, it appears as if it were within a few inches of the eye. Does age weaken the sight? a convex glass restores it again; if the eye be so formed as not to be capable of viewing distant objects, a concave glass remedies the defect. Have you occasion for heat beyond the strength of the furnace? optics will instruct you how to obtain it from the solar rays. With a prism in your hand you decompose those rays in a most beautiful manner, and shew that the rays of light, which appear to us uncoloured, consist of seven primitive colours.

Amongst the various inventions of human art, there are none so justly entitled to your admiration,

as those which enlarge the powers of vision. And the discovery of optical instruments may be esteemed amongst the most noble, as well as amongst the most useful gifts, which the SUPREME ARTIST has conferred on man. For all admirable as the eye came out of the hands of HIM who made it, yet no organ of the animal frame hath HE permitted to be so much assisted by human contrivance, not only for the uses and comforts of life, but for the advancement of natural science, whether as in microscopes, by giving form and proportion to the minute parts of bodies, as it were to the atoms of nature, imperceptible beforce; or, by contracting space, as by the telescope, and, as by magic art, bringing to view the grander objects of the universe, the immense distances of which had either disguised their aspect, or rendered them quite invisible.*

Yet so singular are the dispositions of men, who term themselves philosophers, that you will find them, on the one hand, denying the existence of all spiritual beings and spiritual agency; and, on the other, sooner than own and acknowledge the unity of design and wisdom, that is evident in all parts of creation, they will embrace the greatest absurdities, and make fire and light to be mere qualities. That light is, however, the action of a material, real substance, will become very evident to you by a few considerations.

1st. The motion of light is progressive, like all other bodies; and it has been proved by astronomers, that it takes about seven or eight minutes in passing from the sun to the earth. This discovery was first made by M. *Romer*, who having observed, that the eclipses of the satellites of Jupiter appeared sooner or later than they ought by theory, according as the earth was nearer to, or farther from,

* Sir *John Pringle*'s Discourses.

Jupiter, concluded from thence that the motion of light was not instantaneous; and by observing the different times of the appearances of these eclipses, according to the different distances of the earth from Jupiter, discovered the time it took up. This theory was further confirmed by a notable discovery of Dr. *Bradley*, of an apparent motion of the fixed stars, and elegantly accounted for by the motion of light.

From Dr. *Bradley*'s observations it appears, that light is propagated as far as from the sun to the earth in eight minutes twelve seconds. And it likewise appears, that the velocity of light is uniform and the same, whether original, as from the stars, or reflected, as from the satellites of Jupiter.

2. Light may be stopped or resisted in its passage from one place to another by the interposition of an opake body, as other fluids are stopped in their courses by the opposition of any solid substance.

3. Like all other bodies in motion, it may be turned out of its rectilinear course, and have the determination of its motion changed; it may be collected into a small, or scattered through a large space.

4. It acts upon the organs of animals, and upon all other bodies, in a similar manner as other fluid substances, striking them with a determined force, communicating to them a certain degree of motion, and separating their component parts.

The velocity of light being known, we should be able to estimate the magnitude of its particles, if we were in possession of good observations of the effect of their momentum. For example, it is found that a ball from a cannon at its first discharge flies with a velocity of about a mile in eight seconds, and would therefore arrive at the sun in thirty-two years, supposing it to move with unremitted velocity. Now, light moves through that space in about eight mi-

nutes, which is two million times faster. But the forces with which bodies move are as their masses multiplied by their velocities: if therefore the particles of light were equal in mass to the two-millionth part of a grain of sand, we should be no more able to endure their impulse, than that of sand when shot point blank from a cannon.*

DEFINITIONS.

The cause and nature of vision is properly the subject of that part of philosophy which is called by the name of *optics*. But as light is a principal instrument in effecting vision, the word optics is used in a more extensive sense, and every thing in philosophy is looked upon as a part of optics, which relates to the nature and qualities of light.

When the word *optics* is used in the stricter sense for the theory of vision, the science of optics is divided into two parts; one part is called *dioptrics*, and the other *catoptrics*.

The laws of *refraction*, and the effects which the refraction of light has in vision, are the subject of *dioptrics*.

The laws of *reflexion*, and the effects which the reflexion of light has in vision, are the subject of *catoptrics*.

These distinctions will, however, be of little use to us, it not being necessary in these Lectures to keep the branches of optics distinct from each other.

Whatever is seen or beheld by the eye, is by opticians called an *object*.

They consider every luminous object as made up of a vast number of minute points; and that each of these points, by an unknown power, sends forth rays of light in all directions, and is thus the center

* *Nicholson's* Introduction to Philosophy, vol. i. p. 256.

of a sphere of light extending indefinitely on all sides. To render this clearer, consider this small brilliant object that I place upon the table, and you will find that you can see it from any part of the room; it is therefore evident, that rays of light must proceed from all parts of it, and extend indefinitely on all sides.

By a *ray* of light, is usually meant, the least particle of light that can either be intercepted alone, whilst all the rest are suffered to pass, or that can be let to pass alone, whilst all the rest are intercepted.

Any parcel of rays diverging from a point, considered as separate from the rest, is called *a pencil of rays*.

By a *medium*, in the language of opticians, is meant any pellucid or transparent body, which suffers light to pass through it. Thus water, air, a diamond, and glass, are called mediums.

One medium is said to be more *dense* than another, when it contains more matter in the same bulk and size: thus glass is more dense than water, water is more dense than air.

A small object, or physical point of an object, considered as propagating light towards a certain part, is sometimes called, *a radiant*, or *radiating point*.

Those rays which proceed from any point at a very great distance, may be considered as *parallel* rays; for the greater the distance of the point from whence rays flow, the nearer do they approach a parallel direction.

OF THE GENERAL PRINCIPLES ON WHICH OPTICAL DEMONSTRATIONS ARE FOUNDED.

To illustrate and explain some of the general principles of optics, I shall darken this room, and only admit the light by a small hole; opposite to the hole I shall place a white screen. Now, if you look

at the screen, you will observe thereon a picture of all the exterior objects which are opposite the hole, with all their natural colours: the colours are faintly depicted; the images of the objects that are stationary, as houses, trees, &c. are fixed and stationary in the picture; while the images of those that are in motion, as those of horses, &c. are seen to move. You observe that the image of every object is inverted; this is occasioned by the rays of light crossing each other as they pass through the hole. The sun shines this moment on the hole, as you may see by the luminous ray proceeding from it to the screen. Now, if either of you will place your eye in this ray, you will find that your eye, the sun, and the hole, are in one and the same straight line. It is the same with every other object which is depicted on the screen. The images of the objects are smaller in proportion as the objects are further from the hole.

Let us now consider a few among the many important inferences that may be deduced from the foregoing experiment.

It must be evident to you, that *light moves or acts in a straight line*; for you saw that your eye, the image of the object, and the object, were always in a right line. This is also plain from the shadows which opake bodies cast; for if the light did not describe straight lines, there would be no shadow: it is equally plain from lights finding no passage through bent tubes.

As the rays of light are constantly propagated in right lines from luminous bodies, whenever I have occasion to represent a ray of light, I shall do it by a straight line reaching from a luminous body to the body illumined; that is, I shall speak of the line which the ray describes, as if it was the ray itself.

It is manifest also that light consists of parts both successive and cotemporary, because in the same

place you may stop that which comes one moment, and let pass that which comes presently after; and at the same time you may stop it in any one place, and let it pass in any other. In other words, the light which falls upon an object all at once, at the same instant, is *cotemporary*; the light which from time to time continues to fall on an object is *successive*, consisting of parts following one another.

A second inference deducible from our experiment is, *that a luminous point may be seen from all places to which a straight line can be drawn without meeting with an intervening obstacle.* This must be evident to you, when you remember that the picture of an object in motion in these experiments was visible as long as it was in a line with the hole and screen.

It follows from hence, that a luminous point, by some unknown power, sends forth rays in all directions; and may be considered as the center of a sphere of light extending indefinitely on all sides.

This you may understand still better by looking at *plate* 1, *(Optics) fig.* 1; where you find the point, O, of the dart is visible to an eye placed in either of the situations A, B, C, D, E, F, G, or their intervals.

If you conceive some of these rays to be intercepted by a plane, then is the luminous point the summit of a pyramid, the body of which is formed by the rays proceeding therefrom; the base is the intercepting plane.

The image of the surface of an object on the screen, is also the base of a pyramid of light, the summit of which is the hole. The rays which form this pyramid cross at the hole, and there form another pyramid, of which the hole is again the summit, but the surface of the object is the base.

An object is visible because all its points are radiant points. Rays of light are incessantly propagated

from every physical point of an object, otherwise the whole object would not be visible; and that all at once, and to all positions of the eye.

For wheresoever a spectator is placed with respect to a luminous body, every point of that part of the surface which is turned towards him, is visible; each point is therefore a radiant point, emitting rays in all directions; and those rays only are stopped in their passage by an interposed object, which would be intercepted upon the supposition that the rays move in right lines.

Another inference which you will make, is this, *that the particles of light are indefinitely small*; for the rays, which proceed from the points of all the objects opposite to the hole, pass through it without confounding or embarrassing each other. Exquisitely minute they must be, when myriads can move all manner of ways without impinging one another; and that this is the case, you cannot doubt, since different bodies, and different parts of the same body are distinctly visible at the same time. How curious must be the texture of the eye to be sensible of those small impulses, and to distinguish at the same time those from different objects!

If you make a hole with a pin in a piece of paper, and look through it, you see all the objects that are before you, be they ever so many; now, since these objects, and each point of these objects, become visible by means of the rays of light coming from thence to the object, you may form some idea of their extreme minuteness. If a common tallow candle be lighted, and set by night on an high tower, it may be seen all round at the distance of half a mile from the tower: wherefore there is no place within a sphere of a mile diameter in which the eye can be placed, where it will not receive some rays from this small flame. Rays of light will pass without confu-

sion through a small puncture in a piece of paper from several candles in a line parallel to the paper, and form distinct images on a sheet of pasteboard placed behind the paper.

*Every ray of light carries with it the image of the point from which it was emitted.** If, therefore, all the rays coming from any point are united in the same order in which they proceeded, or were emitted, there will be a perfect representation or image of that object, at the place where they are thus orderly united.

Another property in the rays of light is their *reflexibility*, or disposition of being turned back into the medium from whence they came; and in this they observe the same mechanical laws with other bodies in their reflexions, that is, *the angle of reflexion is always equal to the angle of incidence.* The truth of this position may be confirmed by many experiments; one or two will be sufficient. Let us return to our dark room, and I shall, by means of a plane mirror without, let a beam of solar light pass through the hole upon this part of the floor: where the beam falls, I put a looking-glass; I now fill the room with dust to render the beam of light more visible, and you see that it is reflected back into the air; and that the inclination of the reflected beam is exactly the same as that of the incident beam. This law may be confirmed by another easy experiment, which I will shew you in the next room. Here is a graduated semicircle, at the center of which is a small piece of looking-glass: I place a small object on the graduated edge of the semicircle, and on the opposite quadrant thereof, and exactly at the same angle, I place the sight. Now, if either of you look through the sight, you will see the object; but if

* *De la Caille*, Leçons d'Optique, p. 24.

you remove the sight-piece a little higher or lower, you will not perceive the object.*

OF REFRACTION.

There is another property of light, which is its *refrangibility*, or disposition to be *refracted*, or turned out of its straight course, in passing obliquely out of one medium into another of different density.

This refraction is greater or less, that is, the rays are more or less bent and turned aside from their path, as the medium through which they pass is more or less dense. Thus, for instance, the rays are more refracted in passing from air into glass, than from air into water; and glass is, you know, much more dense than water; the denser the medium, the more the rays are bent, and approach a perpendicular let fall upon its surface. I would be understood always to speak of the rays which fall obliquely upon these mediums; for those rays which fall perpendicularly do not suffer any deviation, *the refraction only taking place when the rays fall obliquely*, and is so much greater as their incidence is more oblique, and the medium more dense. After having taken the new direction, the ray again proceeds invariably in a straight line, till it meets with a different medium, when it is again turned out of its course.

Take an empty bason, and at the diameter of the bottom fix marks at a small distance from each other; then take it into the dark room, and let in a ray of

* Let A B C be the semicircle divided into 180 degrees, from A to B, and from C to B, 90°; a ray of light from an object, D, falling on the mirror, E, will be reflected at the same angle at F, to the eye at G. If the mirror is moved to the angle of 45°, H, an eye at B will have perceived all the objects reflected from the horizon to 90°, or from B to A, or the angle observed but double of the angular motion of the reflecting mirror. This is the excellent property of the Hadley's reflecting octant, which admits of the arc of 45° divisible into 90°. EDIT.

light; and where this falls upon the floor, place your bason, so that its marked diameter may point towards the window, and so that the beam may fall on the mark most distant from the window. This done, fill the bason with water, and you will observe, that the beam, which before fell upon the most distant mark, will now, by the refractive power of the water, be turned out of its straight course, and will fall two or three, or more marks nearer to the center of the bason.

Make the water in the bason muddy, but not so much so as to destroy its transparency, which you may easily do, by dropping therein a few drops of milk, or dissolving in it some grains of saccharum saturni; then fill the room with dust, and the beam of light will be very visible, both in its passage through the air and the water, and you will observe very distinctly three beams, that of incidence, which, in coming through the hole, falls obliquely on the water; that of reflexion from the surface of the water, making the angle of reflexion equal to that of incidence; and that of refraction, which from the surface where it was bent, moves on in a straight line to the bottom of the bason. All things remaining the same, place a small piece of looking-glass at the bottom of the bason, where the refracted beam falls, and it will thereby be reflected back again through the water, and, in passing out of the water into the air, will be again refracted or turned out of its course.

Another, though very common experiment, will give you a clear idea of the power of refraction; place a piece of money at the bottom of this bason, and walk back therefrom till you cannot see the piece of money; let some water be poured into the bason; and as before you could not see the piece of money where it was, you will now see it where it is not. It is not your eye that has changed place, but

the ray of light has taken a new direction in passing from the water into the eye, and strikes your eye as if it came from the piece of money. This experiment seldom fails to surprize those, who are unacquainted with the properties of light; as they do not comprehend how the filling the vessel with water can make them see an object placed at the bottom, and which was not visible to them before, being concealed by the edge of the vessel.

The advantages we derive from the refraction of light are inestimable: without this property we should have figured glasses in vain, and telescopes and microscopes would not have existed. The refraction of light at the surfaces of transparent bodies was taken notice of by the ancients. *Aristotle* has a problem concerning the apparent curvity of an oar in water. And *Archimedes* is said to have written on the appearance of a ring or circle under water. *Alhazen* the Arabian, and *Vitellio*, thought that the angles of incidence and refraction were in a given ratio; but the proportion they laid down being found erroneous in large angles, the subject was examined more strictly by the moderns. *Kepler* among the rest made several experiments concerning it, and though he missed his aim, his attempts and conjectures were useful to others. After the invention of the telescope, this subject being thought more valuable than before, was farther pursued; and *Snellius* found out the truth: but *Descartes* was the first who published, that the *sines of incidence and refraction*, and not their angles, *are in a given ratio*.

In explaining this subject, as well as in other parts of optics, I must have recourse to diagrams, as the theory will require all your attention; but you will not, I hope, permit the thorns and briars, which interrupt the path of science, to prevent your proceeding therein; for whatever is good can only be ob-

tained by labour; and science, like virtue, disdains the slothful and the negligent.

Let BC, *plate* 1, *fig.* 2, represent the surface of water, or any other transparent medium denser than air. Let A be the point of incidence, in which any ray, coming through the air from F, falls upon the surface of the water, where it is refracted from its straight course AK, into the line AG. About A, as a center with the radius AF, describe the circle BFCKE; at the point of incidence A, erect a perpendicular AD, and produce it downward to E; from F, upon the line AD, let fall the perpendicular FH, and from G, upon AE, let fall the perpendicular GI.

The angle FAD, which the incident ray FA makes the perpendicular DA, is the angle of incidence. The line FH is the sine of the angle of incidence FAD.

The angle GAE, which the refracted ray GA makes with the perpendicular AE, is the angle of refraction. The line GI is the sine of the angle of refraction.

The angle KAG, contained between the line of direction of an incident ray and the direction of the same ray after it is refracted, is *the angle of deviation.*

These things being understood, I may now mention to you the laws of refraction, which have by repeated experiments been found to be general, and without any exception.

1. *The angles of refraction and incidence lie in one and the same plane*, that is, in the plane drawn through the incident ray, and the perpendicular at the point of incidence.

2. *The rays of light are always refracted when they pass* obliquely *from one medium into another, whose density is different from that of the first.*

3. *A ray of light falling obliquely upon the surface of a denser medium is refracted towards the perpendi-*

cular, that is, so that the angle of refraction be less than the angle of incidence: on the contrary, the refraction out of a denser medium into a rarer, as out of glass into air or water, is made from the perpendicular, so that the angle of refraction be greater than the angle of incidence.

4. When a ray of light is refracted out of air into a given medium, or out of a given medium into air, the *sine of the angle of incidence is to the sine of the angle of the refraction in a given ratio*; in other words, there is a certain and immutable law or rule by which refraction is always performed; and that is this: whatever inclination a ray of light has to the surface of any medium before it enters it, the degree of refraction will always be such, that the proportion between the sine of the angle of its incidence, and that of the angle of its refraction, will always be the same in that medium.

Hence if that proportion be known in any one inclination of the incident ray, it is known in all inclinations, and thereby the refraction in all cases of incidence on the same refracting ray may be determined.

When a ray of light is refracted out of air into glass the sine of incidence is to the sine of refraction as 31 to 20, or as 3 to 2 nearly; or out of air into water, as 4 to 3. Hence the sine of incidence is to the sine of refraction, when a ray passes out of water into glass, as $\frac{3}{4}$ to $\frac{20}{31}$, or as 93 to 80.

5. *A ray of light cannot pass out of a denser medium into a rarer, if the angle of incidence exceeds a certain limit*;* that is, when the sine of incidence has a greater proportion to radius, than it has to the sine of refraction.

* These laws, &c. are demonstrated upon the principle, that light is a homogeneal substance; and though light will appear to be compounded of several rays, yet the principles of refraction, &c. are true when applied to rays of any one sort.

A ray of light will not pass out of glass into air, if the angle of incidence exceeds 40° 11′, the sine of which is $\frac{20}{31}$ parts of the radius; or out of glass into water, if the angle of incidence exceeds about 59° 20′. Refraction will be changed into reflexion.

In general, the densest mediums resist the action of light more than those that are rarer, the angle of refraction being smaller than that of incidence: and, on the other hand, the rarest mediums seem to resist it less: and it has been laid down as a law, that all bodies have their refractive powers proportional to their densities, excepting so far as they partake more or less of sulphureous oily particles. Mr. *Brisson* has shewn, in the Memoirs of the Academy of Sciences for 1777, that the refractive power of inflammable bodies, compared together, does not follow the ratio of their densities.

6. *All refraction is reciprocal.* If a ray of light be refracted in passing out of one medium into another; then, if that ray were to return back again, it would be refracted just as much the contrary way: or, if the refracted ray becomes the incident ray, then the incident ray will become the refracted one.

When the angle of incidence is increased, the corresponding angle of refraction will also be increased. If two angles of incidence be equal to each other, the angles of refraction will be also equal. In the same manner, if the one be diminished, the other will also be diminished; so that if one of these angles becomes infinitely small, the other becomes so also.

The direction of a ray is not changed, if it moves through a medium terminated by two surfaces parallel to each other; for as much as it is turned towards any side at its entrance, so much is it exactly turned the other way, as it goes out of the said medium.

While a ray moves in the same uniform medium, it does not change its direction.

OF THE FORCE AND INTENSITY OF LIGHT.

In a free medium the force and intensity of light propagated in parallel rays is always the same.

For in such a medium there is nothing to impede its progress, hinder its action, retard its velocity, or change its direction.

In a free medium the force and intensity of the light, which is propagated by rays proceeding from the same point, are in an inverse ratio of the squares of the distances from this point. This is manifest from the principles of geometry, and I shall soon render it evident to you by experiment.

It scarcely, however, wants any experimental proof; for light radiating from a center, its intensity must decrease, as all rays do that proceed from a center; *i. e.* must necessarily become thinner and thinner, continually spreading themselves, as they pass along, into a larger space, and that in proportion to the squares of their distance from the body; that is, at the distance of two spaces, they are four times thinner, or less intense, than they are at one, and so on, because they spread themselves in a twofold manner, upwards and downwards, and sideways.

If the light, which flows from a point, and passes through a square hole, as b c d e, *plate* 1, *fig*. 3, be received upon a plane, BCDE, placed parallel to the plane of the hole; and the distance, AB, be double of A b; then the length and breadth of the shadow, BD, will each be double the length and breadth of the plane, b d, and treble when AB is treble of A b, and so on; as you may easily prove by the light of a candle placed at A.

Hence luminous bodies, or those that shine with their own light, are considerably brighter than opake

bodies illuminated by them; for opake bodies disperse the light falling upon them in all manner of ways: whence supposing all the light to be reflected, the quantity received by the eye from the opake body, compared with that received from the luminous body, is only as the visible illuminated surface of the opake body to the surface of an hemisphere, whose radius is the distance of the opake body from the eye; supposing the breadth of the pupil to be the same in both cases, and that the sum of the distances of the opake body from the eye, and from the luminous body, differs insensibly from the direct distance of the luminous body from the eye.

Hence the light of the full-moon at a medium is about 300,000 times fainter, or rarer, than the sun's light, when at the same height above the horizon, all other circumstances being the same, as will appear by comparing the moon's apparent disk to the surface of a hemisphere. Whence it is easy to conceive, that since we can bear the sun's heat, we cannot be sensible of any from the moon.

"Though accurate methods may be used for investigating the intensity of the moon's light, they are too abstruse for our Lectures. But the following consideration is level to every capacity: when the moon is visible in the day-time, its light is so nearly equal to that of the lighter thin clouds, that it is with difficulty distinguished amongst them. Its light continues the same during the night; but the absence of the sun permitting the aperture of the pupil of the eye to dilate itself, it becomes more conspicuous."

"It follows, therefore, that if every part of the sky were equally luminous with the moon's disk, the light would be the same as if in the day-time it were covered with the above-mentioned thin cloud. This day light is consequently in proportion to that of the

moon, as the whole surface of the visible hemisphere is to the surface of the moon, that is, nearly as 90,000 to 1."*

We do not know any medium that is free, or perfectly transparent; even the air, the most rare and transparent we are acquainted with, is full of opake particles that impede the light; this is manifest from the phenomenon of a beam of light let in through a small hole in the room, which beam is visible like a luminous cone from every part of the room. This shews, that the whole light does not go forward in its rectilinear course, but that at every point of the medium through which it passeth, some part of it is reflected every way; for the visibility of the luminous cone is caused by this reflexion. The greater faintness of the sun and the moon, when near the horizon, than when elevated higher up, shews also that their light is more obstructed, the tract of air and vapours being longer in one case than the other; the loss of light passing through glass is still greater.

The surface also of bodies both transparent and opake, being for the most part uneven, it necessarily follows, that abundance of light is dissipated even by bodies the most transparent, some being reflected, some refracted towards different parts by their uneven surfaces, whilst other parts are refracted and reflected with some uniformity. This accounts for a person seeing through water, and his image being reflected by it at the same time; and shews why, in the dusk, the furniture in a room may be seen by the reflection of a window glass, whilst objects that are without are seen through it.

The quantity of light contained in any pencil is continually diminished, the greater the distance from the radiant; and this diminution is greater or less,

* *Nicholson's* Introduction to Natural Philosophy, vol. i. p. 166.

according to the greater or less degree of opacity in the medium through which it passes.

This makes it impossible to assign exactly the different proportions of the density of light, at different distances from the radiant; but in all cases, the decrease of the density of light is greater than the squares of the said distances. And this decrease is the reason why objects appear less bright, the farther they are from the spectator.

If none of the rays were intercepted in their passage, the degree of brightness of the picture of an object upon the retina, would be the same at all distances between the eye and the object, supposing the aperture of the pupil of the eye to remain the same. For in that case the magnitude of the picture upon the retina, and the density of light, would increase or decrease together in the same proportion, *viz.* reciprocally as the square of the distances of the eye from the object; and therefore the density of the light upon the retina would be invariable at all distances. For example; when the eye approaches as near again to the object, the picture upon the retina becomes quadruple; and the quantity of light received from the object through the same aperture of the pupil at half the distance is also quadruple; and this being equally spread over four times the surface of the retina, the light is just as dense as before, when the object was at twice the distance.

Luminous bodies shining in the dark, as a lamp or torch, &c. emit to very great distances much more light than in that case is necessary for vision: and though their light suffers a continual diminution by the heterogeneity of the medium, the farther it goes; yet there being still more left than is necessary for vision, their splendor is not sensibly increased or diminished, by lessening or increasing their distances.

Light is not only diverted out of its course by reflexion from the bodies it meets with, but a great part of it is also frequently suffocated, or as it were destroyed by them; for it is manifest, that black or dark bodies reflect much less light than others of lighter colours; and, it is probable, that no bodies reflect all they receive.

The power of the eye to discern objects without inconvenience by different quantities of light is very extensive; for not only objects of different colours, placed in the same light, are seen with equal ease, but even objects so small as the letters of a book may be distinguished and read by a clear moon-light. Now, admitting the surface of the eye's pupil to be ten times greater in a weak than in a strong light, yet the proportion of the weakest light to the strongest, by which the eye can conveniently see objects, perhaps, does not exceed that of 1 to 10,000. How exquisite are our faculties!

Experience shews, that objects appear so much more obscure as they are more distant, and at last cease to be visible: this obscurity arises from the passage of the rays of light through the air, a medium dense and foul enough to obstruct them in a very great degree, and dissipate a prodigious quantity in the interval between the eye and the object. The experiments and calculations of M. *Bouguer* shew, that 100th part of the light is lost at 189 fathoms of horizontal distance; that 7469 fathoms, or about 3¼ leagues, dissipates one third of the light; and that they cease at last to be visible, because the images by their diminution in size and light are incapable of making a sufficient impression on the eye.

By a calculation founded on experiment, M. *Bouguer* has shewn, that of 10,000 rays, that proceeding from a star would reach our eye, if it were not for their passing through the atmosphere, there

reach it no more than are set down in the following table:

Degrees of apparent Altitude.	Number of Rays.	Degrees of apparent Altitude.	Number of Rays.	Degrees of apparent Altitude	Number of Rays.
0	5	8	2423	30	6613
1	47	9	2797	35	6963
2	192	10	3149	40	7237
3	454	11	3472	50	7624
4	802	12	3773	60	7866
5	1201	15	4551	70	8016
6	1616	20	5474	80	8098
7	2031	25	6136	90	8123

M. *Bouguer* has also shewn by experiment, 1. That the light of the sun is about 300,000 times stronger than the light of the full moon, when at its mean distance from the earth.

2. That the light of the sun is not sensible when it is diminished 1,000,000,000,000 times, and of course, that a body is truly opake when it permits only 1,000,000,000,000 part of the sun's light to pass through it.

OF IMAGES AND FOCI.

On account of the extreme minuteness of the atoms of light, it is clear, that a single ray, or even a small number of rays, cannot make a sensible impression on the organ of sight, of which the fibres are very coarse when compared to the rays of light. A great number of rays of light proceeding from the same point or portion of the surface of the body are necessary to render this portion visible. But as the rays of light proceeding from the same point are wider from each other the farther they extend, it has been necessary for particular purposes either

to bring them near and unite them together in a point, or to separate them from each other.

We are able by the assistance of glasses to unite, in one sensible point, a great number of rays proceeding from the same point of an object; the rays, thus united in point, form an image of that point of the object from which they proceed; this image is brighter in proportion as there are more rays united, and more distinct in proportion as the order in which they proceed, is better preserved in their union. On placing a polished and white plane at the place of their union, you will see this image painted in all its proper colours, if no adventitious light is permitted to disturb or render it confused.

The point of union of the rays of light, formed by means of a glass lens or a mirror, is called the *focus* of this glass or mirror. If this union is real, the focus is called a *real focus*, or simply *focus:* it is the place where the image of the object is formed, and proceeds to form another image in the eye, as if it were the real object. If this point of union is nothing more than a point, to which the rays in the new direction which has been given to them tend, but are not actually united, this point is called *an imaginary focus*. It is also the place where the object appears really to be, when several of the rays which have been dispersed, enter in sufficient quantity into the eye to form a sensible image of the object. For an object always appears to be in that place from whence its light seems to come to our eye.

Since every ray carries with it the image of the object from whence it proceeds, it follows, that if the rays, after having crossed each other, and having formed an image at their intersection, are again united after either reflexion or refraction, they will form a new image; and so on for ever, as long as their order is not confounded. We may thus form

images of the same object, as often as we can unite the proceeding rays without confounding them.

It follows, that so long as the progress only of the rays of light are attended to, the image may be considered as the object, and the object as the image; and even a second image, as if the first had been the original object, &c.

The rays of light may be differently disposed relatively to each other, and may be considered as *parallel*, *diverging*, or *converging*.

The rays are parallel when they always keep at the same distance from each other.

Those rays which, in proceeding from a point, continually recede from each other, are called diverging rays.

Those rays are named converging, which, proceeding from various parts, approach nearer to each other in their progress, having a tendency to unite in one point.

When two mediums touch each other, their surfaces must be either *plane*, or *convex*, or *concave*; and the rays which acting together pass through these mediums, may be considered either as parallel, converging, or diverging. We will examine together the effects arising from these different circumstances. In speaking of convex or concave surfaces, I shall only consider those that are spherically such.

OF REFRACTION AT A PLANE SURFACE.

Case 1. *When incident parallel rays pass obliquely from a rare into a dense medium terminated by a plane surface, and from this into the same rare medium again.*

To perform the experiments for this and many other parts of optics, I use that part of the solar microscope that carries the mirror, fixing it, as in the present instance, to a window-shutter; on dark-

ening the room, I can thereby reflect readily the solar rays into the room, and pass them through the tube belonging to the microscope; I can render them parallel, convergent, or divergent, according to the lenses I adapt thereto.

The lens now in the tube makes the pencil proceeding therefrom cylindrical; this pencil, by turning the mirror, falls obliquely on the sides of this box, *plate* 1, *fig.* 5, whose sides are of glass; each end has a circular aperture for occasionally receiving a meniscus, or kind of watch-glass, which may be placed either with the convex or concave side outwards; the box is made water-tight, and is furnished with a cock for more easily emptying it of water.

The ray of light at A, *plate* 1, *fig.* 6, entering from the tube the box filled with water, is refracted to B, and forms there, upon this card placed against the side of the box, a luminous circle, exactly the same size as that which entered the box at A: on removing the card, and letting the ray of light proceed in the air, you see that it goes on in a direction exactly parallel to the incident ray, being of the same size through its whole length.

The two pencils of light EA, EA, after being by refraction bent nearer the perpendiculars p p, p p, move on parallel to each other; and on being again refracted, and separating from the perpendiculars s p, s p, you will find, by measuring the distance between them, that they still retain their parallelism.

From hence it follows, that incident parallel rays passing obliquely from air into a mass of water terminated by a plane surface, preserve their parallelism in entering and going out of the water. The same is true of other mediums which differ in density, but have only a moderate thickness, as in our present experiment.

This may be further illustrated by a diagram, *plate* 1, *fig.* 4. Let ABCD be a solid piece of glass with two parallel surfaces AB, CD, and let the incident ray, EF, be refracted into FG; then will FG be refracted by the second surface into GH, parallel to EF, or in the same direction as EF, because the angle at F is equal to the angle of refraction at G; and therefore the angle of incidence at F will be equal to the angle of refraction at G.

Case 2. *When converging incident rays pass from a rare into a dense medium, and from this again into the same rare medium.*

For this experiment, I put into the tube a lens, somewhat more convex than what we used before; so that the pencil of light that issues from the tube is now in the form of a long cone, whose base is the lens.

I fill the box with water, and present it towards the light, so that the side AD, *plate* 1, *fig.* 7, may be perpendicular to the axis of the cone, and in such manner that the point or extremity of the cone may reach the further side, BC, of the box.

I empty the box of its water, and the cone of light becomes sensibly shorter, terminating as at E. By bringing the box nearer to the window, so that the point of the cone may pass beyond the further side, the cone is no longer of a regular shape, but as it appears at FG, and the point is removed somewhat further distant.

This experiment shews, that the rays of light do not converge so soon when they pass from a rare medium into one more dense; and that, on the contrary, they converge sooner than they would otherwise do, when they pass from a dense into a rare medium. In other words, when converging rays go from a rare into a dense medium, they become less convergent; but their convergence is

increased in passing from a dense into a rare medium.

Thus, *plate* 1, *fig*. 18, the two converging incident rays, *a d*, *b c*, which would meet at e, are bent towards the perpendicular by the refracting surface I H, and therefore proceed to E.

In the same manner the converging rays, *l* g, *f* g, falling upon I H, are refracted to *h*, *h*, intead of going on and meeting at *i*: but, on the contrary, in proceeding from the refracting surface K L, the ray, g *h*, g *h*, are refracted from the perpendicular, and therefore meet sooner, as at *K*, than they would otherwise have done: the rays are therefore twice bent, but in contrary directions, once at *h*, *h*, once at g, g.

Case 3. *When incident diverging rays enter into a dense or rare medium.*

Every thing being disposed as in the last experiment, I present the side of the box, AD, *plate* 1, *fig*. 8, when empty, to the cone of light, so that it may coincide with the point of the cone G, which is where they begin to diverge, and will proceed on at B C, and form another cone directly opposed to the other, falling upon a white screen, placed at about four inches from the further side of the box. I measure this cone, and then fill the box with water; the cone then becomes of an irregular shape; the base on the screen is somewhat larger than it was before, but it is not so large at B C as it was before.

From hence we infer, that diverging rays become less diverging in passing from a rare into a dense medium; and, on the contrary, that their divergence is increased by passing from a dense into a rare medium.

Let us consider the diagram, *plate* 1, *fig*. 18, K h, K h, diverging rays meeting the refracting surface L K, do not proceed directly to G G, but are

refracted, and approach the perpendicular, and go towards g and g, and are thus less divergent.

On the contrary, if they proceed from the dense medium, they are refracted, and go towards l and f, which render them more diverging, being twice bent at h and g, and thus forming an irregular cone.

Hence the image of a small object placed under water, is one-fourth nearer to the surface than the object. And hence the bottom of a pond of water is one-third deeper than it appears to the spectator above. An object at E, *plate* 1, *fig.* 18, would appear at c. This may serve as a useful caution to those among you, who are not swimmers, and prevent your plunging unwarily out of your depths.

If you immerse a stick perpendicularly in water, until the immersed part appears of an equal length with the part above; then measure the parts, and they will be found to be to one another about as 4 to 3.

Hence also a fish appears higher than it really is, and the marksman, in shooting at it, must make an allowance for this false appearance, or he will miss his object.

If all the parts of an object, seen at some depth in the water, were equally displaced or altered, the image thereof would be exactly similar to the object it represents; for the figure depends on the respective position of the parts, which is not changed by a motion common to the whole. But this is not the case, if the object under water be of any considerable size; for those rays which come from the extremities that are most distant from the eye, fall more obliquely on the surface of the air, and are more refracted, and approach too near the refracting surface to preserve a total conformity of the image with its object. Thus an eye at *K*, *plate* 1, *fig.* 18, viewing at the bottom of the water a straight line, *g c d g*, not only sees the whole

line nearer to the eye than it really is, but the extremities, *g g*, appear nearer than the other parts *d e*; thus it appears curved with the part towards the eye. Thus a straight leaden pipe appears at the bottom of the water to be curved, and at the bottom of a flat bason deeper in the middle than at the sides.

Very thick dense mediums make objects appear larger than they really are; thus a fish appears larger in the water than when taken out, as do plants, stones, &c. To comprehend this, suppose for a moment, that *g g*, *plate* 1, *fig.* 18, are the extremities of an object seen at the bottom of the water, by the rays *g h*, *g h*. An eye placed in K judges of the size of the object by the angle G K G, larger than that of g *K* g; and the same happens with respect to every part of the object viewed through a denser medium than air.

Hence it is, that objects in a different medium from that where the spectator is, generally appear somewhat distorted.

OF REFRACTION AT A CONVEX SURFACE.

1. *When parallel rays pass out of a rarer into a denser medium, whose surface is convex.*

Before we proceed to make any experiments or reason upon them, I must observe to you, that lines drawn from the center of a spherical surface are always considered, by mathematicians, as perpendiculars to that surface, and the angles they make with the angles of incidence are the angles of inclination. So that as light passing into a denser medium, is so refracted as to approach the perpendicular, or line drawn from the center of the spherical surface to the point of incidence; so in going from a dense into a rare medium, the rays separate from the same surface.

I place the glass box so that the pencil of light falls directly on the convex glass at the end, and you see that as soon as I pour water into the box, the rays converge, and meet in a point: so that parallel rays in this case are rendered convergent; a circumstance that naturally arises from the laws of refraction, see *plate* 1, *fig*. 9; for the parallel rays *h i*, *f g*, *plate* 1, *fig*. 19, falling obliquely on the convex refracting surface, *g*, E, i, are bent towards the perpendiculars *i c*, or *g c*, those lines being the perpendiculars to the points of the convex surface, on which the two given rays fall, and tend to unite at the axis AB. You will also take notice, that those rays which are furthest from the axis unite at points nearest the refracting surface; thus the ray, *f g*, falls upon the axis at *k*, but the ray, *d e*, does not meet it till it arrives at D; hence all those, which are not too distant from the axis, may be considered as uniting in one point.

2. *When converging rays, passing out of a rare medium, fall upon the surface of a denser medium with a convex surface.*

I bring the box as before with the convex glass towards the ray of light; but in such manner, that the converging point of the pencil shall fall exactly on A, *plate* 1, *fig*. 10, the center of convexity. I pour water into the box, and you find that there is no change in the situation of this point, because there is no obliquity of incidence.

Let us now try the effect with two other cones of light, one terminating at *b*, *plate* 1, *fig*. 11, nearer the convex surface than its center, the other being beyong the center of convexity at *c*, *plate* 1, *fig*. 12; mark exactly the place where the cone terminates in each of these cases, when there is no water in the box, and then fill it with water, and observe the difference in each case. You will find the first cone,

fig. 11, where the rays tended to unite at *b*, before they reached the center of convexity, lengthened, and the point thereof terminating at a greater distance, B; but the cone, *fig.* 12, where the rays tend to unite at a point *c*, beyond the center of the convex surface, is shortened, terminating at C.

These experiments have made you masters of the fact; I shall now consider the three cases in a diagram. It is evident, that if converging rays fall upon a convex surface, they either tend to unite at the center of convexity; or 2dly, their point of union will be nearer the refracting surface than that center; or 3dly, it will be beyond that center.

In the first case, the rays do not deviate: thus the rays *e f*, *d h*, *plate* 1, *fig.* 20, converge at c, just as they would have done without the interposition of the refracting substance, because they do not possess the property necessary for refraction, namely, obliquity of incidence. For, the rays, *e f*, *d h*, tending to c, the center of the surface, may be considered as radii prolonged, and consequently as perpendicular to the convex surface.

In the second case, where the rays tend to unite nearer the surface than the center of convexity, they become less converging; for the ray *i h*, *plate* 1, *fig.* 20, which tends to k, is bent by the refracting surface nearer the perpendicular *d* c, and is thus removed further from the surface, and joins the axis at o.

In the third case, where the rays tend to unite beyond the center of convexity, they become more converging: thus the ray *g h*, *plate* 1, *fig.* 20, tending to *l*, further from the convex surface, *h b f*, than c, by approaching the perpendicular *d c*, is brought nearer the center, and joins the axis at *p*, where it would be met by another ray falling upon the surface with the same degree of obliquity, but

from the other side of the axis. This is the more common of the three cases.

3. *When diverging rays, passing out of a rare medium, fall upon a dense one with a convex surface.*

To shew what happens with these rays, we have only, as before, to place the box so that the diverging rays may fall upon the convex surface, and to receive the light upon a plane surface in the box, and to mark the size of the luminous circle formed thereon, before we pour any water into the box. This being done, I shall now fill our box with water, and you will perceive, that the luminous circle is considerably smaller than it was before, *plate* 1, *fig.* 13. If you remove the box further from the point from which the diverging rays proceed, the base of the luminous cone will still grow smaller, and at last become cylindrical; and if you go on removing it still further, they will converge in a point.

From these experiments we draw the following conclusion: That diverging rays, in passing from a rare medium into a denser with a convex surface, become less divergent, which may be carried so far, that they may become parallel, and even convergent.

The diverging rays, *a m*, *a l*, *plate* 1, *fig.* 21, meeting with the refracting surface *m b l*, do not proceed in straight lines to *f* and *e*, but are refracted towards the perpendiculars *e* C, *c* C, which gives them the directions *m g*, *l h*, much less divergent.

If the rays that fall on the refracting surface, as *d m*, *i l*, are less diverging than the preceding, they will be refracted so as to converge at B.

Let us now suppose *the rays of light passing from a denser medium into a rare one, the dense medium being terminated by a convex surface on the side of the rare medium.*

Parallel rays are thereby made to converge: thus the parallel rays, *d e*, *g i*, *plate* 2, *fig.* 2, falling on

the refracting surface, *e i*, instead of proceeding to *f* and *h*, are bent further from the perpendiculars *a* C, *b* C, so as to converge at *k*.

Converging rays become more converging: thus the rays *l e*, *n i*, which would without refraction go on towards *m* and *o*, are so refracted as to unite at *p*.

If the rays are diverging, the point from which they diverge is, 1st, either C, the center of the convexity *e* D *i*; or 2dly, a point *r*, between the center and the convex surface; or 3dly, a point *q*, beyond that center.

In the first case, the rays C *a*, C *b*, are not refracted, because being radii they fall perpendicular to the convex surface.

In the second case, where the rays, *r e*, *r i*, proceed from *r*, they do not go on towards *s* and *t*, but are refracted further from the perpendiculars *a* C, *b* C, and go on towards *x* and *y*, diverging more than before.

In the third case, the diverging rays, *q e*, *q i*, become less diverging, and instead of proceeding towards *z* and *z*, they get closer together towards *g* and *h*, being refracted further from the perpendiculars *a* C, *b* C, and may be rendered parallel, or even convergent, according to the greater or less degree of divergence, when they arrive at the surface *e* D *i*.

OF REFRACTION AT A CONCAVE SURFACE.

1. *When parallel rays of light pass from a rare medium into a dense one, with a concave surface.*

One end of the box, *plate* 1, *fig.* 5, is furnished with a glass with the concave surface outwards; this is now to be presented towards the cone of light. In the present instance, let parallel rays fall on the concave surface. Having observed the size of the

luminous circle formed by them within the box, fill the box with water, and you will find that the pencil of light is enlarged, and the luminous circle is much increased. See *plate* 1, *fig*. 14.

That parallel rays necessarily in this instance become diverging ones, may be also rendered clear by a diagram. For, the parallel rays, *a b* and *d e*, *plate* 2, *fig*. 1, falling upon the concave refracting surface *e*, *h*, *b*, are by refraction made to approach the perpendicular *f* C, *g* C, which renders them diverging.

2 *When converging rays pass from a rare medium into a dense one, terminated with a concave surface.*

We proceed, as in the foregoing experiment, observing where the converging rays terminate, before and after water is poured into the box, and that with different degrees of convergency.

You see, however great the convergency of the rays may be, that as soon as the water is put into the box, the cone is sensibly lengthened, *plate* 1, *fig*. 15. With a less degree of convergence, they are sensibly separated from each other; so that, by altering the degree of convergency, we render them either parallel or diverging. To view this in a diagram, you may consider the rays *a b*, *d e*, *plate* 2, *fig*. 3, tending to converge at O; these are by refraction made to approach the perpendiculars *f* C and *g* C, and thus do not unite till they come to *i*.

3. *When diverging rays pass from a rare medium into a dense one, terminated by a concave surface.*

Every thing being disposed as in the last experiment, remove the box, so that the point where the rays meet or cross, and begin to diverge, may fall upon the center of the concave glass; receive the base of this cone on a plane placed at about seven or eight inches from the glass; measure the diameter, and fill the box with water.

Repeat the experiment with the concave glass nearer C, *plate* 1, *fig*. 16, and afterwards further from it.

In the first case, the size of the circle is not enlarged, nor the cone of light altered. In the second, the base of the cone is smaller in the water than it was in the air. In the third, it is somewhat enlarged. See *plate* 1, *fig*. 16 and 17.

In the first case, the rays undergo no alteration, because they have no obliquity of incidence, for C *b* and C *e*, *plate* 2, *fig*. 4, are radii of the concavity, and continue their rout to *f* and *g*, as they would have done without the interposition of a refracting medium.

In the second, they become less divergent, for the two diverging rays, *k b* and *k e*, instead of going to *d* and *h*, proceed to *a* and *e*, the refraction making them approach the perpendiculars *f* C, *g* C.

In the third case, which is the most general, the rays become more diverging; for *l b* and *l e*, which tend towards *m* and *n*, are turned out of their way towards *i* and *o*, by approaching the perpendiculars *f* C and *g* C, and thereby become more diverging than they were before.

Let us now suppose that the rays of light pass from a dense medium into a rare one, and that the dense medium is terminated on the emergent side by a concave surface.

The parallel rays become divergent, for the parallel rays *d e*, *g i*, *plate* 1, *fig*. 22, in emerging from the concave surface *e* D *i*, do not continue their rout in straight lines towards *f* and *h*, but are carried towards *m* and *p*, by separating from the perpendiculars C *a*, C *b*, which renders them divergent.

If the rays are converging, they may be divided into three cases. 1. When the point of convergency tends precisely to the center, C, of the concavity *e* D *i*; in this the rays, *a e*, *b i*, do not suffer any re-

fraction; because being the continuation of the radii C *e*, C *i*, of the concavity *e* D *i*, there is no point of oblique incidence.

2. When the rays, *q e*, *r i*, tend to converge to the point *n*, nearer the concave surface, *e* D *i*, than its center C, by separating from the perpendiculars C *e*, C *i*, they unite at o, and are thus rendered more converging.

3. When they tend to a point, *l*, which is further from the concave surface than the center of curvature, they are rendered less convergent. For the rays *s e*, *t i*, which tend naturally to converge to the point *l*, by separating from the perpendiculars C *e*, C *c*, unite in *k*, further off than they would have done without refraction, if they were only a little converging; on arriving at the concave surface *e* D *i*, the refraction may render them parallel or diverging.

The diverging rays E *e*, E *i*, diverging from the point E, which without the change from the medium would go on towards *u* and *x*, but by the refraction separating from the perpendiculars C *e*, C *i*, they are turned towards *y* and *z*, diverging more than before.

OF GLASS LENSES.

By a lens, opticians mean a transparent body of a different density from the surrounding medium, and terminated by two surfaces, either both spherical, or one plane and the other spherical. And as the lenses for optical uses are generally made of glass, it is usual to call them *glasses*, with the addition of the use they are intended for, as *a magnifying glass*, *a spectacle glass*, *an object or eye-glass of a telescope*, &c.

Glass was probably the invention of some manufacturer, having nothing else in view but raising a fortune by his new manufacture: but from hence we are supplied with telescopes, microscopes, and

prisms, which let us into secrets of nature unsuspected before, open to us the immeasurable grandeur of the universe, and bring us acquainted with animals, to whom a spoonful of vinegar serves for an habitable world; thereby raising our idea of the Author of Nature, by displaying the magnificence and wonders of his works. From hence likewise has proceeded gradually a more exact knowledge of the laws of attraction, the velocity of light, the existence of ether, and the extreme rarity of bodies. Thus the unlearned are often made to lend an helping hand to the contemplative in the prosecution of his science.

A lens having one side plane and the other convex, is called a *plano-convex*; where one side is plane and the other concave, it is a *plano-concave*. A lens terminated by two convex sides, is called *double-convex*; *a double-concave*, if terminated by two concave sides. A lens having one side concave, the other convex, is called a *meniscus*, or a *concavo-convex lens*. See *plate* 2, *fig*. 9.

From these definitions you will readily conceive, that there may be an infinite variety in the degrees of convexity and concavity; for a convex surface may be conisdered as forming a part of a sphere; and as the radius or diameter of this sphere is greater or less, the convexity will be different.

Hence when I say that the radius of the convex surface of a glass is three inches, I mean that it is the portion of a sphere whose radius is three inches. To render this subject clearer, here are a variety of lenses of different convexities; from these you see, that the smaller the radius is, the more the surface is curved, or the greater is its deviation from a straight line. On the contrary, the longer the radius, the more it approaches to a plane; so that a plane surface may be considered as similar to a convex surface of an infinite radius.

To explain the effect produced in the appearance of objects, by convex and concave lenses, we must distinguish two cases: 1. Where the object is at a considerable distance from the lens. 2. Where the object is near the lens. Before, however, I enter upon this explanation, it will be necessary to define what is meant by the axis of a lens. A straight line drawn perpendicular to both the sides of any lens is called the axis thereof;* the axis therefore passes through the center of the spherical sides; and as we represent the two surfaces by arcs of a circle, you have only to draw a line through their respective centers, and it will represent the axis of the lens. Thus the center of the arc AEB, *plate* 1, *fig.* 23, is at C, that of AFB at D, and the line, CD, is the axis of this lens; it is easy to see that the axis passes through the middle, and that no lens, excepting a sphere can have more than one axis, because no other line can pass through the two centers C, D; and therefore all pencils are considered as oblique, excepting those whose foci are in the axis of the lens.

As the axis is perpendicular to the two surfaces, it is plain from the nature of refraction, that a ray of light passing in this direction is not refracted, but goes on in the same direction in which it entered.

No ray that passes through the center o, *plate* 1, *fig.* 23, of a lens is refracted; for the two tangents at E and F are parallel, and the effect is therefore the same as if the ray passed through a piece of glass whose sides are parallel.

I shall now proceed to consider the nature of double convex lenses. It is the property of these to

* If one of the surfaces be plane, the axis of the lens falls perpendicular upon the plane surface, and proceeds through the center of the spherical one.

make parallel rays converge to a focus; to increase the convergence of converging rays; to diminish the divergence of diverging rays, and that so much under certain circumstances, as to render them parallel or convergent.

Let us consider AB, *plate* 1, *fig*. 24, as a convex lens, whose axis is the line O E F P; and let us suppose that on this axis, and at a great distance from the glass, there is a luminous point or object, O, diffusing its rays in all directions; some of these, as O M, O E, and O N, will fall upon the glass, the middle one, O E, will not be refracted, but pass on in the direction E F P. The two other rays will be refracted and bent both at entering and going out, so as to meet at J, somewhere on the axis, and then go on in the direction J Q and J R: the other rays between M and N, will be so refracted as to unite on the axis at the same point J. Thus the rays O M and O N, and those between them, which without the interposition of the glass would have followed their respective rectilinear directions, are so bent thereby as to follow other directions, and proceed as if they came from the point J; and an eye placed at P would be affected in the same manner as if the luminous point was at J; the glass, AB, forming an object at J, exactly representing the object at O. Thus a considerable change is produced by the lens; a distant object, as O, is as it were transplanted and brought suddenly to J.

Let us now consider the effect produced on the rays of light, when the object is very near to the lens. In *plate* 2, *fig*. 13, M N represents a double convex lens, O A B T S the axis of the lens, O P a distant object situated on the axis; every point of this object diffuses rays in all directions; of these, we are only concerned with those that fall upon the lens: and to render the subject clearer, I shall only

consider three rays, O A, O M, O N, proceeding from the point O; of these the first, O A, passing through the middle of the lens, its direction is not altered, but continues, after it has passed through, to go on in the line B T S, the axis of the glass. But the other two, O M, O N, are so refracted both at entering and quitting the lens, that they unite at T on the axis, from whence they again proceed in the directions M T Q, N T R, so that if an eye were to meet with them, they would produce the same effect thereon as if the object, O, had been situated at T. To distinguish, however, the true point, O, from the point T, the first is called the object, the other the image of that object, which image in its turn becomes also an object. When the object is at a considerable distance, the point, T, is considered as the focus of the glass. The following remarks on this point are necessary to be considered with attention:

1. When the point O, or the object, is at an infinite distance, the rays, O M, O A, O N, may be considered as parallel to each other and to the axis of the lens.

2. The focal point, T, is a point behind the glass, where parallel rays falling upon that glass are united by the refractive power of that lens.

3. The focus of a lens, and the place where the image of an object situated in the axis of the lens, but at an infinite distance from the lens, is represented, are the same thing.

4. The distance of the point, T, from the lens is termed the focal distance.

5. Every convex lens has a particular focus; in some it is greater, in others less; which is easily found by exposing the glass to the sun, and observing where the rays unite.

6. Those lenses which are formed by the arcs of small circles, have their foci very close to them, and

the focal point is further off in proportion as the surface or sides of the lens are formed by arcs of a longer radius.

7. In order to form a proper idea of the optical effect of any lens, it is necessary to know its focal distance.

8. When parallel rays, A B, C D, *plate* 3, *fig.* 4, fall upon a plano-convex lens, D e B, and pass through it, they will be so refracted, as to unite at a point, F, behind it; this point is called the principal focus, and its distance, e F, from the middle of the glass its focal distance, which is equal to twice the radius, or the diameter of the sphere's convexity, of which the lens is a segment.

9. When parallel rays, AB, C D, *plate* 2, *fig.* 5, fall upon a glass, DeB, equally convex on both sides, and pass through it, they will be so refracted as to unite in a point or principal focus, F, whose distance is equal to the radius or semi-diameter of the sphere of the glass's convexity.

The rays in both cases cross the middle ray, d e, in the focus F, and then diverge from it to the contrary sides, in the same manner as they converged in coming thereto. See *plate* 3, *fig.* 4 and 5.

If another double convex lens, h g, *plate* 3, *fig.* 5, be placed in the rays at the same distance from the focus, they will be so refracted thereby as to proceed from it in a parallel direction, as at h b, g c, going on in the same manner as when they fell upon the first glass; but on contrary sides of the middle ray D c F f f; For the ray, A B F, will go on in the direction F h b, and the ray, C D F, in the direction F g c; and so of the rest.

To render the progress of the rays from an object through a lens to the image behind more evident, I have constructed a model, in which the rays are represented by silken strings; that it may be more

clear, the rays issue only from three points, and only three rays from each of these points.

In *plate* 4, *fig.* 9, we have a figure of this model. ABC is the object placed somewhat beyond the focus of the convex lens d e f. The rays, A*d*, A*e*, A*f*, flowing from the point A, are refracted into the directions *da*, *ea*, *fa*, meeting in the point *a*. The rays, B*d*, B*e*, B*f*, proceeding from B, pass through the glass, and are so refracted as to unite at *b*. In the same manner, those that flow from the point, c, are conveyed and meet at *c*; at each of the points *a*, *b*, *c*, an image is formed of the respective points A, B, C. The same takes place with all the other intermediate points, by which means a perfect image of the object is formed, but in an inverted position.

I have already observed to you, that an object at an infinite distance has its image formed at the focus of a convex lens, provided the object be situated on the axis of the lens. I shall now proceed to consider nearer objects, but still situated in the axis; and you will find, the nearer the object approaches the glass, the further the image is removed therefrom.

Thus, let us suppose that F, *plate* 2, *fig.* 11, be the focus of the lens *m m*, or place where the image of a distant object is represented. If the object be brought successively to P, Q, and R, the image will be successively removed further from the glass to *p*, *q*, and *r*; the distance B*r*, &c. of the image always corresponding to that of the object AP, &c. Mathematicians give rules for calculating these distances;* we can only now observe in general, that the more we diminish the distance of an object from the lens, the more that of the image is increased, which

* Multiply the distance of the radiant point by the radius of convexity, if the lens be double and equally convex; divide the product by the difference between the said distance and radius; the quotient will be the focal distance required. For a plano-convex, you take twice the radius. EDIT.

will be rendered plainer by an example, suppose of a lens of six-inch focus; that is, if the object is at an infinite distance, the focus will be precisely at six inches; but when the object approaches the lens, the distance of the image will increase, as in the following table:

Distance of the object.	*Distance of the image.*
Infinite	6 inches
42	7
24	8
18	9
15	10
12	12
10	15
9	18
8	24
7	42
6	Infinite.

Although the numbers only agree with a lens of six inches focus, yet we may deduce the following consequences from them:

1. If the object be at an infinite distance, the image will be at the focus.

2. If the object be at double the distance of the focus from the glass, the image will also be at double the distance of the focus from the glass; thus in the foregoing example, when the object was at twice 6, or 12, the image was also at 12 inches.

3. When the object is at the same distance from the glass as the focus, the image is removed to an infinite distance on the opposite side.

4. In general, the distance of the object and the image correspond reciprocally to each other; so that if the object be placed where the image was situated, the image will be found where the object was before placed.

5. If the lens, AB, collect in J, *plate* 1, *fig.* 24, the rays which emanate from the point O, it will also collect the rays from the point J, and consequently the rays may be returned back in the direction in which they proceeded. This article is of considerable importance towards a thorough knowledge of the nature of lenses; thus for example, when I know that a lens has represented, at eight inches from it, the image of an object which is at 24 inches on the opposite side, I may conclude, that if the object be at eight inches, the image will be at 24.

When the object is situated at the focal distance from the glass, the image is suddenly removed to an infinite distance therefrom.

You inquire of me, what then becomes of the image, when the object is within the focal distance? can it be removed to a distance greater than infinite? this is impossible. The question, though not easily resolvable by metaphysics, does not embarrass a mathematician; for he proves that the image in this case passes to the other side of the glass, and is found of the same side with the object.

In every representation formed by lenses, there are two circumstances to attend to; one concerning the place where the image is formed, the other, the size of the image. Having explained the first, I now proceed to consider the second. Let O P, *plate* 2, *fig.* 14, be an object situated on the axis of the convex lens M N; find first the point I, where the rays proceeding from O, meet the axis; this done, we have to find where the other point, P, will be represented.

To do this, consider the rays P M, P A, P N, which proceeding from P, fall on the lens, and you see that the direction of the ray, P A, is not altered, because it falls upon the middle of the glass, but continues to proceed in the line A K S; it will therefore be somewhere in this line, as at K, that the rays

P M, P N, will meet, and K will be the image of the other end of the object; the point K being determined by a place where a perpendicular to I O from I, meets the line P S, and I K will be the image of the object. It is evident from this, that the image is inverted; so that if Q R was horizontal, and the object, O P, a man, in the image the feet would be upwards, and the head downwards. It is also clear,

1. That the image is always small in proportion as it is nearer the lens, and larger the further it is removed therefrom. Thus O P, *plate* 2, *fig*. 15, being the object, and M N the lens, the image will be smaller if formed at Q, than if it were formed at R, S, or T; that is, the image is larger the further it is from the lens.

2. There is a case where the image is precisely at the same distance from the lens as the object, which is when the object is placed at twice the focal distance from the lens.

3. When the image is twice as far from the glass as the object, it becomes double the size of the object, and in general the image is so many times larger than the object, as it exceeds it in distance from the lens: now, the nearer the object is to the glass, the more the image is removed from it, and is consequently so much larger.

4. On the contrary, so much as the image is nearer to the glass than the object, it is so many times smaller than the object. If then the distance of the image from the glass was 1000 times less than that of the object, it would also be 1000 times smaller.

OF BURNING-GLASSES.

The sun, as we all experience, is the cause of heat at the surface of the earth; its effects are most violent in those regions where its rays fall with

the least obliquity, for they arrive there with greater force, and in a greater quantity. Winds meet and destroy each others forces, but the rays of the sun travel onward without impeding each other in their progress.

All substances feel the influences of the solar rays, not only in proportion as they strike against them more or less directly, but according also as they are fitted for their reception. For the rays, though they continue ever to operate, are restrained from acting too fiercely, by the nature and disposition of the bodies on which they fall, and their own equable diffusion. To give the rays greater power, they must be collected by art; and when their action is concentrated, they consume or change all bodies with inexpressible force.

One of the first uses to which convex lenses were applied, was that of collecting the rays of the sun, in order to set wood or other combustible matter on fire.

The sun is so far off, that we may consider every point upon its surface as at an infinite distance, and may therefore suppose the rays emitted from each point to be parallel to each other; consequently, all the rays from the sun that fall upon a convex lens, will, by passing through the glass, be made to converge, and unite in a focus behind it.

The effect of the rays of the sun, when they are thus collected, is the reason why the point where they are collected is called the focus: and the name, after it had for this reason been given to this point, has been made use of as a general one to stand for any point, where converging rays meet, or to which they tend.

Every lens, whether convex, or plano-convex, will collect by refraction the rays of the sun dispersed over its surface into a point, and thus become a burning lens. To understand this, let M N, *plate* 2,

fig. 15*, represent a convex lens, receiving on its surface the rays, R, R, R, of the sun; these are refracted by the lens into a small luminous circle at F, which is the image of the sun.

As all the rays which fall upon the lens are united in its focus, their effect ought to be so much more, as the surface of the lens exceeds that of the focus. Thus if a lens four inches broad collect the sun's rays into a focus at the distance of one foot or twelves inches, the image will not be more than one-tenth of an inch broad. The surface of this little circle is 1600 times less than the surface of the lens, and consequently the sun's light must be so many times denser within that circle; it is not therefore surprizing, that it burns with a degree of ardour and violence exceeding any culinary fire.

That the ancients made use of burning-glasses is evident from a passage in a play of *Aristophanes*, called the Clouds, where *Strepsiades* tells *Socrates*, that he had found out an excellent method to defeat his creditors, if they should bring an action against him. His contrivance was, that he would get from the jewellers a certain transparent stone, that was used for kindling fire, and then, standing at a distance, he would hold it to the sun, and melt down the wax on which the action was written.

The most considerable of these glasses are those that were made by M. *Tschirnhausen* and Mr. *Parker*. Though I have already mentioned* both to you, it may be worth while to enter into somewhat a larger detail of their effects. The diameter of that of M. *Tschirnhausen* was three feet, the focus was formed at twelve feet, and its diameter one inch and an half, and weighed 160 pounds. To render the focus more vivid, it was collected a second time by a lens

* Vol. i. p. 464.

placed parallel to the first, and so situated, that the diameter of the cone of rays, formed by the first lens, was exactly equal to the diameter of the second lens; so that it received all the rays, and the focus was contracted to eight lines, and its force was increased proportionably.

The lens made by Mr. *Parker*, of Fleet-street, was formed of flint glass, is three feet in diameter, and, when fixed in its frame, exposes a clear surface of two feet eight inches and an half in diameter, weight 212 pounds, focal length six feet eight inches, diameter of the focus one inch. A second lens was used, which reduced the focus to half an inch.

I shall now recite some of the principal effects of that made by M. *Tshirnhausen*, having already noticed those of Mr. *Parker*'s.

1. Every kind of wood catched fire in an instant, whether hard or green, or soaked in water.

2. Thin iron plates grew red-hot in a moment, and then melted.

3. Tiles, slates, and all manner of earth, grew red in a moment, and vitrified.

4. Sulphur, pitch, and all resinous bodies, melted under water.

5. Fir wood exposed to the focus under water, did not seem changed; but, when broken, the inside was burnt to a coal.

6. If a cavity was made in a piece of charcoal, and the substances to be acted upon it were put in it, the effect of the lens was much increased.

7. Any metal whatsoever thus inclosed in the cavity of a piece of charcoal, melted in a moment, the fire sparkling like that of a forge.

8. The ashes of wood, paper, linen, and all vegetable substances, were turned, in a moment, into a transparent glass.

9. The substances most difficult to be wrought on were those of a white colour.

10. All metals vitrified on a china plate, when the china plate was so thick as not to melt, and the heat was gradually communicated.

11. When the copper was thus melted, and thrown quickly into cold water, it produced so violent a shock, as broke the strongest earthen vessels, and the copper was entirely dissipated.*

The experiments with a burning-glass, among other things, prove, that fire is regularly diffused through all space, and perfect therein; and that when properly directed and put in action, it burns with a vehemence superior to any culinary fire. The fire was in the expanse before the glass was applied; and the surface by which it was collected and directed, only put that fire in action, which already existed.

Mr. *Parker* observed a violent rotatory motion in the rays at the focus, which rotatory motion became visible on a small mass of gold when melted; for it instantly assumed a motion round its axis, and that invariably the same way as the earth moves round its axis. The velocity of this motion was accelerated, if at any time the sun shone with greater brightness than before.

Though the heat of the focus was so intense as to flux gold in a few seconds, yet there was no heat at a small distance therefrom; and the finger might be placed in the cone of rays, within an inch of the focus, without receiving any hurt. Mr. *Parker* had the curiosity to try what the sensation of burning at the focus was, and having put his finger there for that purpose, he says, it neither

* When plates of copper are cast at a foundry, after the moulds have been well heated and dried, they wrap them round with blankets to prevent the access of any moisture, which would not only dissipate the metal, but blow up the works, and even overturn the house itself.

seemed like the burning of a fire, nor a candle, but the sensation was that of a sharp cut with a lancet.

You may, by means of the focal rays from this glass, char or burn a piece of wood to a coal in a decanter of water, and yet the sides of the decanter, through which the rays pass so very near the focus, will not be cracked, nor any ways affected; nor will the water be in the least degree warmed. The wood was afterwards taken out, and the rays thrown on the water; but no continuance of collected rays in this way, would either heat the water or crack the glass; but if a piece of metal be put into the water, it soon becomes too hot to be touched, and communicating its heat to the water, makes it not only warm, but sometimes causes it to boil.

Though the water alone is not affected; yet when a little ink was poured into it, the water began to boil in a very little time.

OF THE SCIOPTIC BALL, OR CAMERA OBSCURA.

By *camera obscura*, opticians mean any darkened room, out of which all the light is excluded, but what comes through a lens upon a white screen properly placed, on which the objects seen without are depicted.

It is in general made in two different ways: one is, a large room or chamber, made as dark as possible, with the scioptic ball containing the lens fixed in the window-shutter: the other is small, and made in various ways, as that of a box, a book, &c. for the conveniency of carrying it from place to place; whence it is called the portable camera obscura, and is useful to a young artist in taking the optical view of any proposed prospect.

It is by means of convex lenses that we obtain all the advantages that are derived from the camera obscura, which exhibits, in a most pleasing manner,

all the objects seen without in their natural proportions, colours, and motions, as vivid and beautiful as life; which I shall shew you as soon as I have explained the nature of the instrument.

Let W, X, Y, Z, *plate* 2, *fig.* 6, represent a darkened room or box, well closed on all sides, so as to admit no light but what comes through the lens o, whose focus is such, that the images of the objects from without fall exactly on the wall B, or on a white paper screen placed to receive them.

In the diagram, to prevent confusion from too many lines, only three pencils are drawn, one from each of the extremes P, R, the other from the middle Q, of the object P Q R; and in these pencils there are only drawn the axis, and the two extreme rays.

But the rays that flow from any point, as P, for instance, upon the lens are innumerable, the whole conical space, b P d, being filled with them. These are all collected and united at the focus p, and there received upon the white paper, and are reflected by it in all manner of directions; so that to a spectator in the room, p is now, as it were, a real object, exactly similar to the physical point P, in proportion to it, as O p to O P, and p is of the same colour with P, because the rays flowing upon the lens from P, are united at p, distinct and separate from the rays coming from other parts of the object.

Every other physical point of the object sends forth its cone of rays, which are united by the lens, orderly at p, q, r, and being there reflected by the screen, the image of the whole object is distinct and visible, like a picture drawn upon canvas; but much more lively and distinct than the best finished drawings of the greatest artist.

If the objects are very remote in proportion to the focal length of the lens, we shall have the pictures of those that are in the same neighbourhood, pretty

distinct at the same time, though they are not exactly at the same distances from the lens; because, in that case, the focal distances of the refracted rays differ only insensibly.

There will be as many foci upon the paper as there are radiant points in the object from which the rays proceed; and these foci will be disposed in the same manner, in respect of one another, as the radiants. Those foci will be the most bright in which the most rays are united, and those will be the least bright in which the fewest rays are united.

Now the most rays will be united in those foci, which correspond to the radiants, from which the most light proceeds; and the fewest will be collected in those focal points, that correspond to radiants from which the least light proceeds. Therefore, the light and shade upon the paper will be answerable to the light and shade upon the surface of the object.

When the rays from these foci are reflected by the paper, and enter the eye of a spectator, who looks at the paper, he will there see the picture, or likeness of that object; for the figure made up of these foci will be like the figure of the object, because the focal points are disposed in the same manner, with respect to one another, that the radiants in the objects are. The light and shade upon the paper are every where answerable to the light and shade upon the surface of the object. And the colouring of each particular part through the whole figure upon the paper, is the same with the colouring of the correspondent part in the object.

If the screen be moved nearer the lens, as to x, or farther from it, as to y, the picture will be confused, because the rays proceeding from the next adjacent objects begin to interfere and mix together, as the rays from *a* will be mixed with those from P. The distinctness of the picture, we have observed,

is entirely owing to the separation of the rays belonging to every point of the object upon their reception on the screen. If the screen be removed farther and farther from the focus, the picture will become more and more indistinct, and at length totally vanish, no one part being distinguishable from the rest; for all the rays, that proceed from the several points, must go to as many correspondent points to make a complete image of the object. The brightness of the picture, when its distance from the lens is given, is in proportion to the area of the lens. The distinctness of the picture is not the same thing as its brightness; nor is the confusion of parts the same thing as its obscurity.

The brightness of the picture in every part depends on the rays that come to that part, and that the picture will be bright or faint in proportion as it is formed by more or fewer rays. Now the quantity of light, or number of rays that pass from any given object into the room, is greater or smaller in proportion as the hole through which they pass is greater or less, or as the area of the lens is greater or smaller.

The foot of the cross will be at *r*, and the top at *p*, for every object must be represented at the place where a line falls, drawn from the object through the middle of the lens; and, consequently, what is at the top will be represented at the bottom; and objects to the right will have their images to the left in the picture.

Why the image is inverted is evident from a bare inspection of the figure; and it is also evident, that this inversion is not owing absolutely to the lens; for if that be removed, and the light be admitted through a small hole in the shutter, as you saw at the beginning of this Lecture, we shall have an inverted picture on the screen, though very imperfect when compared to that formed with the lens: the several

pencils in both cases cross each other; but, without the lens, the picture is very faint and confused; it is faint for want of sufficient light, so many rays from each point not being collected together; it is confused, because the rays that proceed from the adjacent objects interfere and mingle together.

Let us now proceed to try the scioptic ball, *plate* 2, *fig*. 16. To use this, the window-shutters must be made to shut quite close, and all crevices stopped, as we have done here, by nailing slips of cloth close over them; the sash is thrown up, and we have cut a hole in the shutter sufficient to let the ball move freely therein: to this we shall screw our instrument, which consists of three parts, a frame AB, a ball of wood C, and a glass lens. The flat side of the frame is to be screwed close to the window-shutter; the frame consists of two parts, the flat board with a hole in it, and a screw, to which a ring is adapted, by which thé ball is confined; it moves with more or less ease, as this ring is screwed more or less tightly; the ball has a large cylindrical hole at each end, which is cut to a female screw for receiving the lens fitted in a cell. By the motion of the ball, the axis of the lens may be turned different ways; and the sphericity of the frame and ball prevents any light being transmitted between them. There are usually two lenses of different focal lengths; by using both together you obtain a third, but with less light, having a shorter focus than either singly. There is a paper screen, and a plane glass, polished on one side, with proper supports, so that I may place either of them exactly in the focus, by moving them backwards and forwards till the picture is distinct. The images are more vivid on the rough glass. There are two brass fastening screws *a a*.

This instrument may be considered as a kind of artificial eye; the frame may represent a frustrum

of the orbit of the eye, and the wooden ball, which is moveable every way therein, the globe of the eye; the hole in the ball represents the pupil, the convex lens corresponds to the crystalline humour, and the screen to the retina; all which you will better comprehend when we explain the nature of vision. I fix the scioptic ball in its place, and darken the room, and set the screen at a proper distance from the lens.

You see what a beautiful and lively picture of all the objects before the window is exhibited on the screen. It may with propriety be termed nature's art of painting. You have perspective here in perfection, or a just diminution of objects in proportion to the distances, the images being all in proportion to the respective apparent magnitudes of the objects seen by an eye at the hole in the window. The colouring here is just and natural, the light and shades perfectly just, and the motions of all objects are perfectly expressed; the leaves quiver, the boughs wave, the birds fly, &c. as in nature, though much quicker, and in a lesser scene. From the camera obscura, the painter may learn his defects, see what he should do, and know what he cannot perform.

OBSERVATIONS ON THE SCIOPTIC BALL.

All other circumstances being the same, the pictures of all objects that are near, as within five, ten, or twenty yards, are more vivid than those that are more remote. Universally, the picture will be more distinct and pleasant, when the objects are at such moderate distances, in proportion to the focal length of the lens, as to exhibit small parts, as the features of a person's face, the tiles of a house, &c. If the light without is favourable, and the spectator has been some time in the dark, it is surprizing how dis-

tinct and vivid objects will appear, that are diminished at least twenty or thirty times; and a person may be known, when his features are proportionably no bigger. The lights and teints are then exquisitely delicate and perfectly just, and the relievos of objects quite bold. A distant prospect appears perfect enough, but is not so entertaining.

All light should be excluded from it but what comes through the lens; for, in proportion as the field about is darker, the objects will appear brighter, as the stars do in a dark night. The spectator himself should also be in the dark, at least while he looks at the picture; for, by this means, the pupils of his eyes enlarge; and, as they enlarge, the apparent brightness of the picture will increase; and, being free from extraneous light, the impression on the retina will be more vivid and sensible. The objects should also be well enlightened, otherwise the pictures will be dull, obscure, and no ways agreeable. You must therefore never exhibit but in a clear day, and it will answer best when the sun shines upon the objects; that is, if the prospect be western, the appearance will be best in the morning; if eastern, in the afternoon; if northern, about noon. A southern aspect is the worst of any for the camera obscura in northern latitudes, and *vice versa*.

A proper aperture should be given to the lens; if the aperture be too small, the picture will be dark and obscure, and upon that account indistinct and unpleasant. If the aperture be too large, the picture will be indistinct, on account of the aberration of the extreme rays, of which we shall speak hereafter; and also because the picture will be too much enlightened by the adventitious light which enters the room, by which it is much obscured and injured.

The apertures will admit of some latitude, and may be more or less contracted, as the objects are

more or less illuminated, or as they are nearer or farther from the lens.*

After every attempt to improve the picture, the apparent brightness will decrease nearly as the square of the focal length of the lens is increased. For this apparent brightness will be nearly as the density of the light in the picture, divided by the density of the adventitious light in the room. And whatever is the focal length of the lens, the density of the adventitious light will be nearly as the square of the linear aperture of the lens; and to preserve the same density, the aperture must be as the focal length.

In some cases the breadth of the picture may be about two-thirds of its distance from the lens, and even more if the paper be made a little concave; that is, the picture may take in a field of near forty degrees; but in most cases, when the field is so large, the picture will be more distinct in the middle than towards the extremes, and therefore you should seldom exceed an angle of about twenty or thirty degrees.

A glass having both its sides ground flat, nearly parallel, and polished on one side, will exhibit the images of objects considerably more vivid and distinct, than by reflexion from paper, &c. The rays are not so much dissipated in this case, as they are by reflexion from the opake surface; you are also less offended by extraneous light, as none is admitted but what falls upon the glass, and passes through it, and you may therefore have a good pic-

* The aperture should be varied according to the brightness of the day and favourableness of light upon the object. The operator should, by experiment, diminish or enlarge it as may be found best. The following are the extreme apertures to each focus, that in general are found the most proper, subject to the state of light upon the objects: 18 inches focus, $1\frac{1}{2}$ inch aperture; 3 feet, 2 inches aperture; 4 to 6 feet, $2\frac{1}{2}$ to 3 inches aperture; 7 to 12 feet, $3\frac{1}{2}$ to $4\frac{1}{2}$ inches aperture, &c. EDIT.

ture by a much deeper or shallower lens than you have on the paper.

The inverted position of the images shewn by this camera obscura is an imperfection; they are not so pleasant to the eye as when erect, and a person cannot be known so readily in an inverted picture, as after the same picture is set in its proper position. But if you take a looking-glass, and hold it before you with the face towards the picture, and inclining downwards, the images will be erect in the glass, and appear with greater lustre than in the screen; or you may place a small plane mirror, D, before or behind the lens, to inflect the rays, before they come to the picture, down upon a white painted table or paper.*

OF THE MAGIC LANTHORN, *plate* 3, *fig.* 2.

The magic lanthorn has been generally applied to magnify small paintings on glass in a darkened room for the amusement of children: we shall shew you, by other new-constructed sliders and machinery, that it may be applied to more important purposes, by using it with such figures as will explain the general principles of optics, astronomy, botany, &c.

* *Plate* 3, *fig.* 1, represents the portable camera obscura, made sometimes of dimensions suitable to the pocket. At the front, A, is a convex lens, refracting the rays from the objects, upon the plane mirror, placed diagonally at B, which inflects them up to the rough and polished glass at *C*, where the external objects are beautifully represented in miniature, animate as well as inanimate. The shutter, D, is for excluding the external light. An additional lens is sometimes fitted at A, to accommodate the instrument for exhibiting profiles, &c. of persons situated in a room. A convex lens has also been applied under the rough glass C; this renders the images more vivid, but less defined at their contours. Red French chalk may be used for delineating images on the glass C, and then, by pressing the white paper on the glass, the figure is transferred to the paper.

For larger camera obscuras to exhibit the images upon white drawing paper, the construction of others, and the description of other optical machinery, not noticed by our Author, see my Appendix to Lecture XVI. EDIT.

The construction and theory of this instrument is simple; it consists of a tin lanthorn with a tube fixed to the front; this tube contains an inner one, which slides into the other; by drawing the outermost out, or pushing it in, the tube may be made shorter or longer. At the end of this moveable tube a convex lens is fitted; the picture which is painted with transparent colours on glass, is placed in a groove made in the immoveable part of the tube, so that as the tube is lengthened or shortened, the lens will be either at a greater or less distance from the picture. In the inmost of the tubes, and as close to the side of the lanthorn as possible, is placed a thick convex lens, in order to cast a strong light from the lamp upon the object.

To be more particular; in the inside of the lanthorn, *plate* 3, *fig.* 2, is a lamp L, whose light passes through the great plano-convex lens N K L, and strongly illuminates the object Q R, which is a transparent painting on glass, inverted and moveable before the lens M K, by means of a sliding frame in which the glass is fixed. The illumination is often increased by means of a concave mirror, X, placed at the back of the lanthorn. If, when the object is properly illuminated, the lens, at S T, be moved a little further from the object, at Q R, than its focal distance, it will form, at a great distance on the opposite wall, the image V W; which will be as much larger than the object Q R, as the distance, Z O, is greater than Z G. As the lens, S T, is moved farther out of, or pushed into the tube, the image, V W, will be smaller or larger, and according to the distance of the opposite wall.

To render the picture distinct, no light should fall upon it but what passes through the lens, and for this reason the lanthorn must be used in a darkened room. The object placed inverted in the lanthorn, as the lens Z, by refraction, depicts them inversely on the

screen. In the lanthorns now made, the aperture for the slider, Q R, is placed before both the lenses at M K L, but apparently with no advantage.

FURTHER REMARKS ON THE PROPERTIES OF CONVEX LENSES.

Convex lenses are used for magnifying objects: to comprehend this, we must consider their nature a little further. I have already told you, that when an object is very distant, the image is represented at the focus of the glass; and that the image is removed further from the lens, in proportion as the object approaches it; so that if the object is at the focal distance from the lens, the image is removed to an infinite distance. And for this reason, the rays, O *m*, O *m*, *plate* 2, *fig*. 8, which issue from the point O, are refracted by the glass, so that they become parallel to each other, as N F, and N F; and as parallel lines may be considered as proceeding to an indefinite distance; and that the image is always where the rays, which proceed from the object, are united after refraction; in the case where the distance, O A, of the object is equal to the focus of the glass, the image is removed to an infinite distance. As it is indifferent whether the parallel lines, N F, N F, meet on the right or left hand, the image may be considered as being on either side, but at an infinite distance. From hence you will easily conclude where the image will be found, when the object comes still nearer the lens than the focus.

Let O P, *plate* 2, *fig*. 10, be the object: now, as the distance, O A, thereof from the lens is less than the focal distance, the rays, O m, O m, which proceed from the object, are too diverging to be rendered parallel by refraction; but continue divergent, as N F, N F, after they have passed through the glass, but much less so than before; so that by pro-

longing them on the other side the lens, they will meet somewhere, as at *o*; consequently, N F, N F, after refraction, follow the same direction as if they proceeded from the point *o*, and an eye which receives these rays will be affected as if they came from *o*, and will imagine that the object of vision is at *o*, where there will be no image formed; and in vain would you apply a screen there to receive it.

But an eye at E receives the same impression as if the object, O P, existed at *o*. It is therefore important, in such cases, to know the size and place of the *imaginary* image *o p*. With respect to the place, it will be sufficient to remark, that if the distance from the object, A O, was equal to the focal distance of the glass, the image would be at an infinite distance; but as the object is brought to the lens, the more the imaginary image also approaches the glass, yet its distance always exceeds that of the object from the glass.

To illustrate this by an example; let the focal distance of the glass be six inches, and the following tables will give you the distances of the object, as well as the corresponding distance of the imaginary image *o p*.

Distance of the object A O.	*Distance of the imaginary image* A *o*
6	Infinite.
5	30
4	12
3	6
2	3
1	$1\frac{1}{5}$

The rule for finding the size of the imaginary image *o p*, is easy and general. Continue F N, F N, the refracted rays, till they meet at *o*, in the axis *o* O A. Draw a line, C P *p*, through the extremity

of the object and C the center of the glass, and at *p*, where it meets the line *o p*, perpendicular to the axis of the glass, you find *o p* for the size of the imaginary image: from whence you see, that this image is always larger than the object; and that in proportion as its distance from the glass exceeds that of the object from the glass: you also see, that the image is not inverted.

From these observations you will comprehend the use of convex lenses to persons who do not see near objects distinctly, but see well those that are at a distance; for by help of these glasses they see near objects as if they were at a distance.

OF CONCAVE GLASSES.

As convex glasses cause the rays of light to converge and unite, so those which are concave make them separate and diverge; for which reason, if diverging rays fall upon a concave lens, they will diverge more after they have passed through it than before; and such rays as converge before their incidence, will, after their passage, converge less, in effect directly contrary to that of convex lenses.

Let us consider their nature by a diagram, *plate* 2, *fig*, 12. Let TV represent a double concave lens, and O P an object at a great distance, so that the rays, O M, O M, may be deemed parallel. These falling upon the concave glass are thereby rendered more divergent, and go on in the directions, N F, N F, as if they had proceeded from the point *o*, although they really proceed from O.

As the rays are deemed parallel, if the glass had been convex, *o* would have been the focus; but since there is no real concurrence of the ray, this point is termed the *imaginary* focus of the concave lens, and sometimes the point of dispersion, as the refracted rays seem to diverge from this point.

Concave glasses have, therefore, no real focal point, but one that is imaginary, whose distance, A *o*, however, is termed the focal distance.

When the object, O P, is at an infinite distance, the imaginary image, *o p*, is represented at the focal distance of the concave lens, and on the same side as the object; but though this image is imaginary, the eye is affected in the same manner as if the rays proceeded from that point.

When the object is nearer the glass, the image *o p* also approaches it; but so that the image is always nearer the glass than the object; whereas in convex glasses it is further from the lens than the object. To make this clearer, let us suppose, that the focal distance of the concave lens be six inches; the

Distance of the object O A.	*Distance of the image* O A.
Infinite	6
30	5
12	4
6	3
3	2
2	$1\frac{1}{2}$

The same rule as I gave you before determines the size of the image, by drawing a line from the center of the glass to the extremity of the object, which will pass by p, the extremity of the image; this image is not inverted. Indeed, it is a general rule, that the image is always upright when it is on the same side of the glass as the object. The figure shews you evidently that in concave glasses the image is always less than the object.

You may now see why concave glasses are of such use to short-sighted persons, or those who only see near objects distinctly; for they will represent distant objects to them in the same manner as if they were really very near.

A *meniscus* has the properties of a convex lens, when the inner radius is the greater; and of a concave, when the inner radius is the smaller. If the two surfaces are concentric, it has neither of the properties; for the rays will then emerge parallel. If the radius of convexity be less than the radius of concavity, then the meniscus will have all the properties of a convex lens of the same focal distance. If the radius of the concavity be less than the radius of convexity, then the meniscus will have all the properties of a concave lens, whose focal distance is the same.

When any small object, or any point of that object, is seen by refracted light, it appears in the direction of that line which the rays describe after their last refraction.

If the rays that come from any small object pass through a glass prism, of which ACB, *plate* 3, *fig*. 6, is a section, the ray, DE, will be refracted towards a perpendicular when it enters the prism, and will describe the line EF; and when it goes out of the glass it will be refracted from a perpendicular into the line FG; which line is the direction of it after its last refraction, and the object, D, will be seen at L, instead of D: for this and all other cases of the same sort, the picture of the object on the retina will be in the same place that it would have been if the eye had been really looking at an object placed at L; for the refraction gives the rays the same direction as if they had come originally from L.

From hence we understand, why an object seen through a multiplying glass, or through a glass that is cut into different surfaces inclined to one another, appears at one view in many different places. If the object, B, is seen through the glass, abcd, *plate* 3, *fig*. 7, by the ray, AB, that passes through the surface cb, the object by the eye at A, will be seen at B; the ray, Bd, passes through the surface cd, and, when it is refracted, comes to the eye in the direc-

tion AD, as if it proceeded from D, and therefore the object appears at D; and for the same reason through the surface, ab, it appears at C; consequently there will be the appearance of as many objects as there are such surfaces on the glass, for each of them shews the same object in a different place. If such a glass be shaken or turned round before the eye, the apparent objects on the other side will appear also to shake or turn round, as the situation of the rays by which it is seen will be varied with every motion of the glass.

In refracted vision, it is not the object itself we see, but the last image of it, which consists of all the imaginary radiants, or points, from whence the rays appear to diverge after their last refraction. That you may the better understand what I here mean by the last image, let *plate* 3, *fig.* 12, be an object nearer to a convex lens than its principal focus. The rays that diverge from any point, b, in this object will, by passing through the lens, be made to diverge less, and the imaginary radiant will be more remote than the real one. Thus the rays b g, b l, when they have gone through the lens, will not proceed straight forward in the lines g k, l p, but will be refracted into the less diverging directions g m, l n, as if they had come from the imaginary radiant e, which is more remote than the real one, b. The same will happen to the rays that come from a, or c, or any other point in the object; so that there will be somewhere behind the lens, as at df, as many imaginary radiants as there are real ones in the object; and these imaginary radiants taken all together compose the last image. And since all the rays fall upon the eye, as if they had diverged from this last image, the eye will be affected by the object, a b c, just in the same manner when it looks through the lens, as it would be without the lens, by an object in all respects like d e f, or as it would be by the last

image, if without the lens the last image could be made visible; and because the eye is affected when it looks through the lens, as if d e f was the object, and not a b c; therefore we say, that it is not the object itself, but its last image that we see.

This is universal; in refracted vision, the eye is affected by the rays of light after refraction, as if they had come not from the object itself, but from its last image, which consists of all the imaginary radiants from whence the refracted rays appear to diverge at the same time they fall upon the eye.

TO FIND THE FOCAL LENGTHS OF LENSES BY EXPERIMENTS.

1. When the focal length of the lens does not exceed two or three feet, it may be found by holding the lens at such a distance from the wainscot opposite a window sash, that the image of the sash may be distinct upon the wainscot, and this distance may be considered as the focal length of the lens; but if the focal length is long, you must compute the focus by the subsequent rule.

Rule. Measure the distance between the lens and the object, and also from the image; multiply these distances together, and divide the product by their sum; the quotient will give the focal distance. Or, the square of the distance of the observed focus, divided by the distance of the object from the image, will give the excess of the observed focus beyond the true focal distance.

2. When you find the focus by making a candle the object. To do this, move the lens or the candle, and the paper for receiving its image, so that when the image is most distinct the lens may be exactly between the other two; then halve the distance between the object or its image, and the lens is the focal distance.

3. If a small hole about one-fourth or one-eighth of an inch be made in the window-shutter of a darkened room, and a lens and piece of paper be held behind this hole at proper distances, the place where the image of the hole is most distinct may be determined very critically, and from thence the focal length may be found by the foregoing rule.

4. By the sun's image. Place the lens so that its axis may point as near as possible to the sun; then holding a paper opposite thereto, the burning point, or where the image of the sun is smallest and the limb most distinct, is the focus. This method is sufficiently accurate for spectacle glasses and reading glasses, and such as are broad in proportion to their focal length; but will not answer for lenses of a long focus, unless they are sufficiently long to exhibit the solar spots; because in these cases the image is only a glare of light without distinctness; but the inconveniences may be removed by the following method.

5. Cover the lens with a piece of pasteboard or paper, and make two round holes therein at an equal distance from the edge of the lens, and on one of its diameters. The lens being thus covered, point its axis to the sun: now if a paper be held behind the lens, you will find the two circles or white spots produced by the two holes gradually approach nearer to each other, as the paper is moved further; at last they will coincide; and if the paper be moved still further, they will again separate. The distance of the paper from the glass when the circles unite being measured, gives the focal distance.

TO FIND THE FOCAL LENGTH OF A CONCAVE LENS.

Let the lens be covered with paper, having two small circular holes; and on the paper for receiving

the light describe also two small circles, but with their centers at twice the distance from each other of the centers of the circles. Then move the paper forwards and backwards till the middle of the sun's light, coming through the holes, falls exactly on the middle of the circles; that distance of the paper from the lens will be the focal length required.

TO FIND THE FOCUS OF A PLANO-CONVEX AND A PLANO-CONCAVE LENS.

By similar experiments you will find, 1. That the focus of a plano-convex or of a plano-concave glass is equal to a diameter of its convex or concave surface, that is, of the whole sphere it belongs to.

2. That the focal distance of a double convex or double concave glass, of equal convexities or concavities, is equal to a semi-diameter of either of its surfaces; and consequently that the focal distance of a glass of unequal convexities or concavities, will have an intermediate length between a diameter and a semi-diameter of that surface which is most convex or concave.

TO MEASURE THE FOCAL DISTANCE OF A GLOBE OF WATER AND OF GLASS.

Take a hollow globe of glass, or, instead of it, a thin round flask or decanter, and making a moderate round hole, about an inch diameter, in a piece of brown paper, paste it on one side of the body of the decanter; and, having filled it with water, hold the covered side to the sun, that the perpendicular rays may pass through the middle of the water, and the emergent rays will be collected to a focus, whose nearest distance from the decanter will be equal to the semi-diameter of the body of it, as will appear by receiving the rays upon a paper held at that dis-

tance. That this effect is owing to the water, and not to the glass, will be evident by emptying the decanter; for the light that then passes through the hole, will then be as broad as the hole itself, at all distances of the paper from the decanter. If a similar experiment be tried, with a solid globe or ball of glass, the distance of the focus from the nearest part of the ball will be one quarter of its diameter.

TO FIND THE VERTEX OR CENTER OF A LENS.

Hold the lens at a proper distance from the eye, and observe the two reflected images of a candle made by the two surfaces. Move the lens till these images coincide, and that point is the vertex; and if this be in the middle of its surface, the glass is truly centered, otherwise it is not.

The theory of real images is easily illustrated by experiment. For this purpose I shall draw a long line on the table, and place this convex lens at A, *plate* 2, *fig.* 7, whose principal foci are O F and O f. Now set off these distances on each side of A, and then set off the distance, AF, on the part of the line AB, marking the parts so set off, 1, 2, 3, 4, &c. On fD make f1 equal to Af, and divide it into f$\frac{1}{2}$, f$\frac{1}{3}$, f$\frac{1}{4}$, &c. so that these parts be respectively equal to $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, &c. of f1, or Af: on F1 do the same. This done, let us darken the room, and place a lighted candle, Q, over the division marked 2; the image of the candle will then be seen distinct, but inverted, upon a paper, *q*, held over the corresponding fraction on the other side at $\frac{1}{2}$. If you place the candle at 3 or 4, the paper for receiving the images must be held over $\frac{1}{3}$, or $\frac{1}{4}$, &c. So that if the candle be moved from 2 to an infinite distance, the whole motion of the image will be from $\frac{1}{2}$ to f; if the candle be at 1, the image will be at 1 on the other side. If the candle be brought nearer to

F, the motion of the image and candle will be reciprocal to what they were before. But if the candle be placed any where between F and the lens, there will be no image formed.

OF THE DEGREES OF BRIGHTNESS AND DISTINCTNESS OF AN IMAGE.

Whatever be the shape and magnitude of the hole in the paper that covers part of a lens, the shape and magnitude of the image will be the same as when the lens is uncovered; because any small part of a pencil of rays has the same focus as the whole: but the brightness of the picture will be diminished, in proportion as the hole in the cover is diminished; because the quantity of light which illuminates every point of a picture is diminished in that proportion.

A GENERAL VIEW OF THE PROPERTIES AND PHENOMENA OF SINGLE LENSES, DEDUCED FROM THE PRINCIPLES ALREADY ADVANCED.*

Let R F, *plate* 4, *fig*. 1, be the conjugate foci; P, p, the principal foci. By conjugate foci are meant two points so situated, that either of them being the radiant, the other will be the focus.

Then, 1. Parallel rays falling on one side of a convex lens, A, will be refracted to the principal foci, P, or p, on the other side.

2. Parallel rays falling on one side of a concave lens, A, *plate* 4, *fig*. 2, will by refraction diverge from the same foci, P, or p, on the same side.

3. In a convex lens, rays diverging from P, or p, *plate* 4, *fig*. 1, will emerge parallel on the other side.

4. In a concave lens, *fig*. 2, rays converging to p, or P, will emerge parallel, going out on the same side.

* *Emerson's* Elements of Optics, p. 125.

5. In convex lenses, rays, *plate* 4, *fig*. 1, diverging from R beyond P will converge to F beyond p, and the contrary.

6. In convex lenses, rays diverging from R, *plate* 4, *fig*. 3, which is nearer than P, will diverge from F on the same side with R.

7. In convex lenses, rays converging to F, *fig*. 4, will by refraction converge to R, nearer than P or F.

8. In concave lenses, rays converging to R, *fig*. 2, beyond P, will diverge from F beyond p, and the contrary.

9. In concave lenses, rays converging to F, *fig*. 5 and 6, nearer than p, will by refraction converge to R beyond F.

10. In concave lenses, rays diverging from R, *fig*. 7, beyond p, will diverge from F, nearer than p.

11. In concave lenses, rays diverging from R, *fig*. 8, nearer than p, will diverge from F, still nearer than p.

A meniscus may be considered as convex or concave, according as the center of its inner surface is further off or nearer than the center of the outward surface.

The length of an object is to the length of the image made by a lens, as the distance of the object from the center of the lens, to the distance of the image from the lens.

The area of the object is to the area of the image, as the square of the object's distance from the lens is to the square of the image's distance therefrom.

A convex lens magnifies an object, when it is nearer than twice the principal focal distance; but, if further off, the object is diminished.

A concave lens diminishes the object in all cases.

If the object and its image be both on the same side of the lens, the image will be erect; if they be on different sides, the image will be inverted.

When the object and image are on different sides of the lens, as the object approaches the lens, the image recedes from it; or if the object recedes the image approaches.

If the object and image be both on one side of the lens, if the object moves towards the lens, the image also moves towards it; and the contrary.

In a convex lens, if the object be beyond the principal focus, its image will be on the other side of the glass, and inverted. But if the object be nearer than the principal focus, the image will be on the same side of the glass, and erect.

The distance and magnitude of the image may be increased at pleasure, by causing the object to approach the principal focus.

In a concave lens, the object and image are always on one side of the lens.

The image made by a lens becomes visible by placing the eye to receive the diverging rays, going from the image, at a proper distance for distinct vision.

The image formed in the air by a lens, may not only be seen by the eye placed in the diverging rays, but it may also be seen upon a piece of paper placed at the focus.

If an object be placed at the principal focus of a lens, its apparent magnitude at any place beyond the lens will be invariably the same, and equal to the apparent magnitude when seen from the center of the lens with the naked eye; so that the apparent magnitude of an object placed in the principal focus, will continue, whether the eye be moved nearer to or further from the lens

The nearer the eye is to the lens, the more of the object appears; the farther off, less of it is perceived.

If the object be nearer than the principal focus, its apparent magnitude grows less in going from the glass. If the object be further, the apparent mag-

nitude is increased, when the eye goes further from the glass.

If the eye be fixed at the principal focus, the apparent magnitude of an object will be invariably the same, wherever the object is placed beyond the glass.

If the eye be fixed at a less distance than the principal focus, the apparent magnitude of an object is diminished, though by slow degrees, as it is removed from the lens.

If the eye be fixed at a greater distance than the principal focus, the apparent magnitude of an object is increased, as it is removed from the glass, till it comes to the conjugate focus in respect to the eye, and then it becomes infinite and confused, and begins to be inverted, and going further off again is diminished.

If the eye and the object be fixed, and a concave lens be moved from either of them to the other, the apparent magnitude of the object will decrease to the middle, and then increase again.

The brightness of an image formed by a lens from a luminous object, will be as the area of the lens directly, and the square of the distance reciprocally.

Though the brightness of the image increases with the area of the glass, the distinctness decreases; for it is only the rays very near the vertex that are refracted to a single point in the picture; those that are farther off deviate more and more, and thus render the picture confused.

Other phenomena of lenses will be considered in the course of these Lectures, which cannot be so well treated of till I have explained the nature of vision. You now begin to be acquainted with the properties of another subtile agent, whose particles are immensely minute, whose progress is astonishingly rapid, whose power and influence is beyond comprehension, maintaining an intercourse between

systems, and diffusing numberless blessings in its progress.

You have seen that a body, fit to reflect light and exhibit colours, when placed in the light, not only returns the rays of light that fall upon it, to the luminous body by which it was enlightened, but sends the picture itself quite round the hemisphere in all directions, and to every point. Place a thousand, a million of such bodies, near each other, each performs the same operation; the rays of light and their colours come instantaneous to the spectator's eye from each, without being disturbed or diverted in their passage by the numberless rays returned in different directions by other contiguous bodies. You have seen the vehemence with which this agent, whose parts are so wonderfully minute, acts when its rays are collected by the burning-glass; that no terrestrial substance was capable of withstanding its effects without being destroyed, or decomposed. Some of the effects produced by glasses of different figures have been explained to you. You have also seen objects seemingly suspended in the air, where nothing was to be found that was sensible to the touch. In the camera obscura, you saw nature draw her own picture inverted, and in miniature: you saw a picture painted in a moment with a beauty, a vivacity, and softness of colours, that would make a landscape, drawn by the first artists, appear faint and languid: the picture of the camera was animated, the trees were agitated by the winds, the flocks bounded upon the lawn, and the sun-beams played upon the water: and you learnt, that all these scenes depended upon the refraction of the rays of light, and were made acqainted with the laws of this refraction. In Lecture XVII. you will see these laws applied to explain the nature of vision.

ADDITIONAL DESCRIPTIONS, BY THE EDITOR.

The principal laws of refraction and the properties of lenses have been, for a general knowledge, sufficiently detailed by our Author. To the student, who may not possess the advantage of a previous acquaintance with the mathematics, I recommend actual experiments by various lenses, of different foci, diameters, and colours; from these, and an attention to such models as are represented at *plate* 4, *fig*. 9, 10, 11, and 12, he can exemplify all the general principles of refraction by lenses.

The room should be quite darkened, and the sun's rays admitted through an aperture cut in a shutter, or a tube for that purpose placed therein, and moveable by a ball, such as applied to the scioptic ball and socket, see F, *plate* 6, *fig*. 9, and which might be used for that purpose. His lenses should be fitted in cells, connected to a sliding board or frame, or adapted to stands and frames of wood or brass, as represented at *plate* 3, *fig*. 11. By such contrivances he may combine any sort of lenses together as may be necessary, either separately or close together; he might also have lenses ground to the figure of a meniscus, or of a watch-glass, and connected in one frame, so that fluids might be included, and the properties of refraction by fluid lenses exemplified. A few experiments in this manner will afford the most evident and entertaining modifications of refracted rays. The dust usually in motion will, in the darkened room, give the various and natural figures of the converging and diverging pencil of rays.

Plate 2, *fig*. 5, is a convenient apparatus in brass, placed in a glass jar of water, to prove experimentally the refraction of light out of air into water, and the contrary, or with other fluids. AB represents a brass circular plate, divided into 360 degrees, cut

near to its edge, figured from 0 to 90, from the horizontal line drawn through its center. C, D, are two moveable radii; on one, marked C, are fixed two sight pieces, the holes of which are diametrically directed through the center; on the extremity of the other is fixed only one sight piece, having a white surface, that it may be the more distinctly seen in water.

To use this apparatus, for proving that the refracting medium of water has the proportion of the sine of the angle of incidence to the sine of the angle of refraction, as 4 to 3, as given by the most eminent writers on optics, fix the arm, C, to 40 degrees, and the arm, D, to 30°. Place the apparatus vertically in the jar, and pour in as much water as will fill it up to the center of the circle exactly. When the water is settled, look, through the two sight holes, on C, and you will see the sight hole, marked on D, exactly in a straight line; which proves, that under this proportion of refraction the two radii will appear as one straight line, and that the light from the sight D, by passing from water into air, is refracted in the proportion of 3 to 4.

To determine the refractive power of any other fluid mediums, the sight, D, may be previously put to any number of degrees, and then, by observation, the radius, C, moved till they both appear as one line. The angle thus cut by C will, with the other, D, be the proportion of the angles of incidence and refraction.

In every position, but when the radius, C, is at 0 and 90, when there can be no refraction of the light, the proportion will be proved to be the same.

By fixing a mirror or piece of looking-glass at the center of the brass circle, and turning upwards the radius D, the apparatus will serve to illustrate a primary principle of catoptrics, viz. *the angle of incidence being always equal to the angle of reflexion*, as will be described in the following Lecture.

LECTURE XVI.

OF CATOPTRICS.

After having explained to you, as concisely as I am able, the laws of refraction, and the effect produced by these laws; I shall proceed to explain the doctrine of *catoptrics*, or that part of optics which treats of the reflexion of light. You will here, among other things, learn, how the figure of a man six feet high is seen in a glass mirror not above three feet; how in a convex mirror figures are reduced to a Lilliputian size, and in a concave mirror expanded to a gigantic size; wonders that the curious would wish to comprehend, and the inexperienced to examine.

Before *Newton* published his discoveries concerning the nature and properties of light, it was a principle generally received, that the rays of light were reflected, as other bodies, by striking on their solid and impervious parts, as you see a marble bound when struck upon the pavement. *Newton* taught mankind, that the particles of light are turned back before they touch the reflecting body, by some power which is equally diffused all over the surface of the body.

If, says he, the rays of light were reflected by impinging on the solid parts of bodies, their reflexions from solid bodies could not be so regular as they are; for however polished the smoothest object may seem to our sight and touch, yet it is in fact one continued assemblage of inequalities. For in polishing glass with sand, putty, or tripoly, it is not to be imagined, that those substances can by grating and fretting the glass bring all its least particles to an ac-

curate polish, so that all their surfaces shall be truly plane, or truly spherical, and look all the same way, or compose one even surface. The smaller the particles are, the smaller will be the scratches by which they continually wear away the glass until it be polished; but be they ever so small, they can wear away the glass no otherwise than by grating and scratching, and breaking the protuberances, and therefore polish it no otherwise than by bringing its roughness to a very fine grain, so that the scratches and frettings of the surface become too small to be visible. From such a surface it cannot be supposed, that rays will be reflected with such uniformity as we usually observe: on the contrary, it is highly probable, that if light were reflected by impinging on the solid parts of glass, it would be scattered as much by the most polished, as by the roughest surface.

It is therefore a problem, how glass, polished by fretting substances, can reflect light in so regular a manner; and this problem is scarce otherwise to be solved, than by saying, that the reflexion of a ray is not effected by the reflecting body, but by some power of the body which is regularly diffused all over its surface, and by which it acts upon the ray without immediate contact, so that it is reflected before it arrives at the surface.

A ray of light can fall but two ways upon a mirror, that is, either perpendicularly or obliquely; and experience has proved, that when light is reflected, the *angle of reflexion is always equal to the angle of incidence.* Thus, suppose *a b*, *plate* 1, *fig.* 25, to be the surface of a plane mirror, if a ray of light, *f c*, falls perpendicularly thereon, it is reflected in the same direction, making still a right angle with the mirror. If it falls in an oblique direction, *e c*, &c. it is reflected in the direction *c d*, making with the mirror the angle of reflexion, *d c b*, perfectly equal to the angle of incidence *e c a*.

I shall prove this to you by two experiments; first, I shall let a ray pass through a hole in a darkened chamber, and fall obliquely upon a plane mirror; you will find, that at equal distances from the point of reflexion, the incident and reflected ray will be the same height from the surface.

It is more accurately proved by the brass circle used before, *plate* 2, *fig.* 5. I place the two radii at equal angles from the diameter: now, if you look through the hole or sight down upon the center of the mirror I have placed at the center of the circle, you will see the point of the other radii; which proves, that the ray which comes from that point is reflected from the center of the mirror to the eye, in the same angle in which it fell on the mirror.

This axiom, that the *angle of reflexion is always equal to the angle of incidence*, holds good in every case of reflexion, whether from plane or spherical surfaces, and that whether they are convex or concave.

All reflexion is reciprocal. If the ray *e c*, *plate* 1, *fig.* 25, after it has been reflected in the line *d c*, is turned back again in that direction, it will be reflected into *e c*; therefore, if *d c b* is the angle of incidence, *e a c* will be the angle of reflexion; and if *e c a* be the angle of incidence, *d c b* will be the angle of reflexion.

This general law, that *the angle of incidence is always equal to the angle of reflexion*, is the foundation of all catoptrics, and is sufficient for demonstrating all the phenomena thereof: other laws are only consequences deducible from this principle, or applications thereof to particular effects.

With reflected, as with refracted rays, it is necessary that several rays should act at the same time, in order to make an impression on our eyes; these rays may be disposed differently with respect to each other: they may be either parallel, convergent, or

divergent; and the surface on which they fall, may be either plane, convex, or concave. Each of these circumstances we shall consider separately.

1. *Parallel rays falling upon a plane mirror are parallel after reflexion.*

The parallel rays, *d b*, *c a*, *plate* 5, *fig.* 1, are reflected from the surface *a b* to *h* and *k*, making the angle of reflexion, *i b h*, equal to the angle of incidence *f b d*, and the angle of reflexion, *g a k*, equal to that of incidence, *e a c*; and consequently from the principle of geometry the two rays, *db*, *ca*, are parallel after reflexion.

This may be proved also by letting two parallel rays, in a dark chamber, fall upon a mirror; and you will find that they retain their parallelism after reflexion in every inclination of the mirror.

2. *When incident diverging rays are reflected from a plane mirror.*

The diverging rays, *db*, *ca*, *plate* 5, *fig.* 2, are reflected to *h* and *k*, and have the same degree of divergence at F, as they would have had at E. If they had gone on in their first direction, the points at F and E are equally distant from the points of contact *a* and *b*; therefore the divergence of the rays is the same after reflexion as before.

3. *When incident converging rays falling upon a plane mirror are reflected therefrom.*

The converging rays *db*, *ca*, *plate* 5, *fig.* 3, if the mirror were not interposed, would meet at E, but are so reflected from *a* and *b*, as to make the angles of reflexion, *gbk*, *eah*, equal to their respective angles of incidence *fbd*, *eac*, and unite in F, a point at the same distance from *a* and *b* as the point E; their convergence after reflexion is therefore the same as before it.

Let us now consider a convex surface, and you will find,

1. *That parallel rays falling upon a convex surface are rendered diverging by reflexion.*

2. *That converging rays, when reflected from a convex surface, become less convergent,* and may be rendered parallel, or even diverging, according to the degree of convexity of the reflecting surface.

3. *Divergent rays are rendered more diverging,* so that a convex surface always tends to scatter the rays by diminishing their convergence and increasing their divergence.

As every curved surface may be considered as formed of an infinite number of small straight lines, which constitute the elements thereof; I shall, to render this subject more clear, represent a convex surface by two straight lines inclined to each other: by thus making the elements conspicuous, you will more readily comprehend why the rays of light, when reflected from a convex surface, take a different direction from what they had when they fell upon the mirror.

Let *bd, plate* 5, *fig.* 4, represent a convex mirror, and *ab, cd,* parallel rays falling thereon; and, because the angles of reflexion, *ebf, hdi,* are always equal, the rays are, as you see by the figure, rendered diverging, and proceed to *e* and *h*.

In the same manner, the converging rays, *ab, cd, plate* 5, *fig.* 5, which, if the mirror *bd* were not interposed, would unite in *m,* have their direction so changed by reflexion, that they proceed to and unite at *l,* much further from the points of contact, *b* and *d,* than the point *m*; and you must perceive from the figure that the inclination of the two elements, *bd,* may be so increased as to render them parallel or even diverging.

Thus the rays, *ab, cd, plate* 5, *fig.* 6, which, without the interposition of the mirror would diverge but very little at *m,* are thereby rendered more di-

verging; so that they are much further apart at *l*, than at *m*.

We have only now to consider the direction of rays of light, when reflected from a concave surface; and here you will find,

1. *That parallel rays are by reflexion made converging.*

2. *That converging rays become more convergent.*

3. *That diverging rays become less divergent.*

A view of the diagrams is sufficient to prove the truth of these propositions.

Let *b d*, *plate* 5, *fig.* 7, represent a concave mirror; the rays *a b*, *c d*, which were parallel before reflexion, are by the laws thereof made to converge in *l*.

The rays *a b*, *c d*, *plate* 5, *fig.* 8, which, without the interposition of the mirror, would unite at *m*, are thereby so reflected as to meet at *l*, nearer the points of contact *b d* than *m*.

Lastly, the rays *a b* and *c d*, *plate* 5, *fig.* 9, which before reflexion were divergent, converge after reflexion, meeting at *o*.

From the principles thus laid down, it is easy to see what will be the effect of mirrors, and to explain the principal phenomena which they occasion. By a mirror, or speculum, we in general mean any substance whose surface is sufficiently polished to reflect uniformly the greater part of the rays which fall upon it, and to exhibit an image of the objects placed before it. They are generally divided into plane, convex, and concave mirrors: there are, besides these, conical and cylindrical, pyramidical and prismatical mirrors.

OF PLANE MIRRORS.

It will be necessary here to remind you of what has been already mentioned; namely, that a pencil

of rays emanating from any given point of space, is the means by which the sight assures us that a body exists at or in that point; it is plain, therefore, that we are liable to deception in that respect; for, if the pencil be so affected by reflexion, or refraction, as to proceed with different divergency or direction, that is, in the same direction as it would have proceeded in if coming from some other point, the sense will refer the place of the object to the point, which is in the direction of the last course of the rays.

In a plane mirror, *ab*, *plate* 5, *fig.* 10, the image of an object, *c*, appears to an eye at *e*, behind the mirror in the direction *eg*, and always in the intersection, *g*, of the perpendicular, *cg*, and the reflected ray, *eg*; and consequently at *g*, as far behind the mirror as the object, *c*, is before it. We therefore see the image in the same place, wheresoever the reflected ray be by which it is perceived; for as a plane mirror does not alter the relative position of the rays which fall on it, the diverging rays proceeding from *c* are reflected towards the eye *e*, by the mirror *ab*, with the same degree of divergence, and have their imaginary point of union, *g*, at the same distance behind the mirror that *c* is before it.

For the same reason a plane mirror does not change or alter the figure or size of objects, but the whole image is equal and similar to the whole object, and has a like situation with respect to one side of the plane that the object has with respect to the other; for the converging rays, K*m*, L*n*, *plate* 5, *fig.* 11, proceeding from the extremities of the object, K L, and falling upon the mirror, *ab*, are reflected towards the eye, *e*, with the same degree of convergence, and consequently shew the image, *kl*, under an angle equal to that by which the object would be seen from the point *i*, if the mirror were not interposed.

From what has been explained, it follows, that if an object, K L, is inclined to a plane mirror, its image, *kl*, will be inclined thereto in a contrary direction.

If an object, AB, *plate* 5, *fig.* 12, be placed parallel to a plane mirror, C D, and at the same distance therefrom as the eye, O; the part of the mirror C D, on which the rays, AC, B D, from the object fall, which are reflected to the eye, will be one-half the length of AB. For the image being as far behind the glass as the object is before it, the rays, OG, OH, are each divided at the middle of the mirror CD, and consequently where they only spread half as much as they would do at double the distance. Therefore, to see the whole of an object in a mirror, the length and breadth of the mirror must be half the length and breadth of the object. Hence, if the length and breadth of an object be given, it is easy to determine the size of a mirror that will shew the whole of an object when placed at the same distance therefrom as the eye.

Hence, a person viewing himself in a plane looking-glass placed upright, will see his image complete in a part of the glass whose length and breadth is equal to half the length and breadth of the corresponding parts of his own body; and this will be always the case at whatever distance he stands from the glass.

A spectator will see his own image as far beyond the speculum as he is before it; and as he moves to or from the speculum, the image will, at the same time, move towards or from him on the other side; but apparently with a double velocity, because the two motions are equal and contrary. In like manner if, while the spectator is at rest, an object be in motion, its image behind the speculum will be seen to move at the same rate. And if the spectator

moves, the images of objects that are at rest will appear to approach or recede from him, after the same manner as when he moves towards real objects; plane mirrors reflecting not only the object, but the distance also, and that exactly in its natural dimensions.

One principle is sufficient for explaining with facility the phenomena of objects seen in a plane mirror. It is this: *That the image of an object seen in a plane mirror, is always in a perpendicular to the mirror joining the object and the image*; *and that the image is as much on one side the mirror as the object is on the other.* With the assistance of this principle and a little geometry, you may readily solve the principal questions that can be proposed on this subject.

The celebrated *Archimedes*, at the siege of Syracuse, is said to have destroyed the ships of *Marcellus* by a machine composed of speculums. Since a plane speculum, in theory, reflects all the light which is incident under the same affections with which it was incident, the rays of the sun coming from a very distant object may be considered as parallel, and will be reflected parallel to each other, and consequently will heat and illuminate any substance in the same manner as if the sun shone upon it. Two speculums which reflect the light on the same substance, will heat it twice as much as the sun's direct light; three will heat it three times as much; and by increasing the number of speculums, a prodigious degree of heat may be produced.

Though a plane speculum is supposed in theory to reflect all the light which falls upon it, yet in practice almost half the light is lost on account of the inaccuracy of the polish, and the want of perfect opacity in the substance of the mirror. Notwithstanding this, M. *Buffon*, in 1747, constructed a burning machine of this kind. It consisted of 168

plane mirrors, each eight inches long and six broad, so contrived, that the focal distance might be varied, and also the number of glasses, as occasion required. In the month of March, 1747, with 40 glasses he burnt a plank at the distance of about 70 feet.

OF CONVEX MIRRORS.

Convex mirrors spread or diverge reflected rays; they render parallel rays diverging; they diminish the convergence of converging rays; in some cases they render them parallel, and even divergent.

Let us suppose an object, *de*, *plate* 5, *fig*. 13, to be placed before a convex mirror, *a b*. Of the two cones of rays proceeding from the extremities of the object, the rays *d p*, and *e p*, which, if the mirror were not interposed, would proceed to and unite at *p*, are reflected less converging on the line *f o*, at *n*; the rays *dk*, *el*, which would have converged at *m*, are reflected parallel to *pq*, *gl*: the two rays *d h* and *ei*, which would have met at *c*, the center of convexity, are reflected back on themselves, because of the perpendicularity of their incidence: they are however diverging; and all the rays proceeding from points beyond the two last will be reflected more diverging, as *rh*, *si*.

In convex mirrors, as well as those that are plane, the image appears always erect and behind the reflecting surface, but differs from it in other respects; for, 1. *The image in a convex mirror is always smaller than the object*, and the diminution is greater in proportion as the object is further from the mirror. This will appear clear to you on considering the properties of a reflecting convex surface, that incident converging rays are thereby rendered less convergent: thus let C D, *plate* 5, *fig*. 14, be an object placed before a convex mirror, *a b*; C*e*, D*d*, two rays proceeding from the extremities of the object; these, if the mirror were not interposed, would converge at *f*; but are reflected by the mirror less converging,

so as to meet at *i*, thus forming a more acute angle; the object appears, therefore, smaller than it would have done if it had been viewed from the point *f*. 2. *The image does not appear so far behind the reflecting surface as in a plane mirror.* Let G, *fig.* 15, be a point of any object from whence a diverging cone of rays proceeds, and falls upon the mirror; these rays are reflected more diverging, and have consequently their imaginary focus or point of union, *g*, much nearer, by which means the image appears to be nearer the reflecting surface than the object; and this effect increases in proportion to the convexity of the mirror. Concave mirrors have a real focus, convex mirrors only a virtual focus, and this focus is behind the mirror, distant therefrom half the radius of its convexity.

The image of a straight object, not too small, and placed parallel or oblique to the mirror, is seen curved in the mirror, because the different points of the object are not all at an equal distance from the surface of the mirror. The point O, *plate* 5, *fig.* 13, for example, of the object, *d e*, is nearer than the rest to the surface of the mirror, the extreme points *d e*, are more distant; they will of consequence be represented behind the mirror, at distances proportional to those at which they are placed before; whence it becomes bent or curved.

OF CONCAVE MIRRORS.

I have already shewn you, that it is the property of concave mirrors to collect the rays of light they reflect, converging parallel rays, increasing the convergence of those that are already converging, diminishing the divergence of diverging rays, in some cases rendering them parallel, and even convergent. These effects are all in proportion to the concavity of the mirror.

The point where the rays unite is called the focus of the mirror; but this focus is not the same for all kinds of incident rays. Parallel rays, *ab*, *de*, falling upon a concave mirror, *m o*, are reflected so as to unite at F, *plate* 5, *fig.* 16, which point is distant from its surface one quarter of the diameter of the sphere of the mirror; this point is called the focus of parallel rays, or true focus of the mirror. Converging rays, such as *fg*, *hi*, are reflected more converging, and unite at K, between the focus of parallel rays and the mirror. Lastly, diverging rays proceeding from a point further from the mirror than the true focal point, as R*m*, R*o*, are reflected converging, and meet at a point, P, further from the mirror than the focal point of parallel rays. But if the point K, from which the diverging rays proceed, is nearer the mirror than the point F, they are diverging; that at *g* would proceed to *f*, and that at *i* towards *h*.

The focus, therefore, of parallel rays is at one-fourth the diameter of the sphericity of the mirror. The focus of converging rays is nearer the mirror than that of parallel rays; but the focus of diverging rays is more distant.

Plane and convex mirrors exhibit their images as if behind the mirror and erect. The effect of concave mirrors is different; they only shew the image behind the mirror and erect, when the object is placed between the mirror and the focus of parallel rays, and then the image is larger than the object. Let AB, *plate* 5, *fig.* 17, be an object placed before a concave mirror E F, but nearer than the focus of parallel rays: the two rays, A*e*, B*f*, from the extremities of the object, would, if the mirror were not interposed, converge in *d*; but are reflected more converging, and unite at D, and there form a larger angle, and of course exhibit the image, *ab*, larger than the object, AB.

This image appears further from the back part of the mirror than the object does from the fore-side. Let A, *plate* 5, *fig.* 18, be a point of any object placed nearer the mirror than its focus, and from which a cone of diverging rays proceeds; these will be reflected less diverging, and therefore have their imaginary focus, *a*, further off, and consequently the image will seem at a greater distance behind the mirror, than the object is from the front of it.

But if the object be further from the mirror than F, for example, at *e*, *plate* 5 *fig.* 18, the rays, *eb*, *ed*, diverging but little, are reflected convergent, and exhibit the image at E; so that if the eye, *o*, recedes far enough to receive the diverging rays from E, it will perceive the image at E, between itself and the mirror. The reason is plain; every enlightened point of an object becomes visible by means of a cone of diverging rays proceeding therefrom; we cease to see it, if the rays become parallel or converging, which happens when the object is further from the mirror than its focal point F; the eye therefore must recede, till the rays, having crossed, become divergent.

This image thus formed is always inverted, as *ba*, the image of BA from the mirror GE, *plate* 5, *fig.* 19; for we cannot see the whole of an object, AB, unless diverging rays from its extremities fall upon the eye; and this cannot in the present instance take place till after these rays have crossed between the object and mirror, by which of course they are inverted.

I shall endeavour to illustrate further, by a diagram, the theory of the foci of rays reflected by a spherical speculum. Through the center, O, of the speculum A, *plate* 6, *fig.* 5, draw an indefinite line BD; bisect OA in F; from the points, O and A, divide the lines, OB, AD, into parts each equal to OF or FA, marked by the figures 1, 2, 3, 4, 5, &c. And from F, take on each side F 1, F $\frac{1}{2}$, F $\frac{1}{3}$, F $\frac{1}{4}$,

&c. each equal to the whole, or $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, &c. of FO, FA. Now, if in the line OB, the point 1, or 2, 3, 4, &c. be the focus of incident rays, the correspondent point 1, or $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, &c. in the line OF, will be the focus of the reflected rays. And, *vice versa*, if the last be the foci of incidence, the former will be the foci after reflexion. In like manner, if 1, 2, 3, 4, &c. in the line, AD, be the foci of incidence, 1, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, &c. will be the foci of reflected rays, and *vice versa:* so that the focus of incidence and reflexion unite in O and A; and their motions from O and A towards B and F, in the one case, and towards D and F, in the other, are exactly similar, F being the focus of parallel rays in both cases.

If in a darkened room a lighted candle be held farther from a concave speculum than its principal focus F, as suppose at 2, its image will be seen distinct, but inverted, upon a white paper held at the corresponding point $\frac{1}{2}$. And if the candle be moved to or from the speculum, so as to retain the distinct image thereof, you will obtain an ocular proof of the theory of the foci of incident and reflected rays; when the candle is at O, the paper will be there also. But, as the image of an object between F and a concave speculum, or any where before a convex one, is on the other side of the speculum, in either case, the experiment of the candle and the paper cannot take place.

If you place yourself before this concave mirror, but farther from it than the focus, you will see an inverted image of yourself in the air between you and the mirror, but you will find the image of a smaller size than yourself. If you hold out your hand towards the mirror, the hand of the image will come out towards your hand, and when at the center of concavity, be of an equal size with it; and you may, as it were, shake hands with this aerial image. If you move your hand further, you will find the hand of

the image pass by your hand, and come between it and your body; if you move your hand towards either side, the hand of the image will move towards the other, the image moving always contrariwise to the object. All this while, those who are by-standers see nothing of the image, because none of the reflected rays that form it enter their eyes. To render this effect more surprizing and more vivid, the mirror is often concealed in a box.

The appearance of the image in the air between the mirror and the object, has been productive of many agreeable deceptions, which, when exhibited with art and an air of mystery, has been very successful, and a source of gain to many of our public show-men. The images of animated and other objects have been by them exhibited in this manner, in such a way, as to surprize the ignorant, and please the scientific, or better informed.*

This pleasing and simple experiment has been exhibited as an illustration of the Newtonian doctrine of space. The experiment shews, that by an image formed in the air, at a certain distance between a concave speculum and a person looking into it, extension and form become an object of sense, where there exists neither solidity nor sensible resistance. But this does not prove that an image can be formed in a vacuum, in empty space, or where there is no matter, unless it can first be proved, that there can be no matter where we are not sensible of resistance. For, on the contrary, it may be inferred from this phenomenon, that those spaces, which in a loose and incorrect sense we call empty, are as full of matter as those in which we find the most solid matter: for, as our corporeal senses can be only affected by matter, they are certainly infallible standards for deter-

* In the Appendix to this Lecture I have given a description of the mechanism of the most curious. EDIT.

mining where matter is; so that you may be as assured of a fullness of matter where you see any thing, though you cannot feel it, as you would be certain there was matter where you felt it, though you could not see it, or though it were of the nature of that matter to be invisible. All kinds of reflected images shew, that wherever an object can be formed to impress the senses of sight, there must be as great a fullness of matter as in the original object, from whence the image was carried to those spaces where it is again renewed.

Mr. *Ferguson* mentions two pleasing experiments to be made with a concave mirror, which you may take an opportunity of trying at leisure. If a fire be made in a large room, and a smooth mahogany table be placed at a good distance near the wall, before a large concave mirror, so that the light of the fire may be reflected from the mirror to its focus upon the table; if you stand by the table, you will see nothing but a long beam of light; but if you stand at some distance, as towards the fire, you will see an image of the fire on the table, large and erect: and if another person, who knows nothing of the matter before hand, should chance to come into the room, he would be startled at the appearance, for the table would seem to be on fire, and by being near the wainscot, endanger the whole house. There should be no light in the room, but what proceeds from the fire.

If the fire be darkened by a screen, and a large candle be placed at the back of the screen, a person standing by the candle, will see the appearance of a fine large star or rather planet upon the table, as large as Venus or Jupiter; and if a small wax taper be placed near the candle, it will appear as a satellite to the planet; if the taper be moved round the candle, the satellite will go round the planet. Numerous and astonishing are the phenomena that may be pro-

duced by concave mirrors: one or two more I shall exhibit, your own ingenuity will enable you to vary them.

Stand up on this stool, and tell me what you see on the pot near the partition. A bunch of flowers. Put out your hand, and lay hold of them. They have evaded your endeavours, and you find that you attempted to grasp a shadow. The sense of sight is certainly subject to the greatest illusion, and this experiment is one among many instances. To explain the mystery, go behind the partition, and you will find that I have placed a mirror exactly facing the hole in the partition. There is also an Argand's lamp so placed, as to throw a strong light on the object, without throwing one on the mirror. The bunch of flowers is situated beneath the aperture in the partition, but inverted so as to receive the light from the lamp. The space between the back part of the partition is painted black, to prevent any reflexion of light from falling on the mirror. The rest is exactly similar to what you have already seen, and what has been already explained.

Take a glass bottle, fill it partly with water, and cork it in the common manner; place this bottle opposite a concave mirror, and beyond its focus, that it may appear reversed; then place pourself still farther distant than the bottle, and it will be seen in the air inverted, and the water which is actually in the lower part of the bottle, will appear to be in the upper. See *plate* 9, *fig.* 1 and 2.

If you invert the bottle while before the mirror, the image will appear in its natural erect position, and the water will appear in the lower part of the bottle: while it is in this inverted state, uncork the bottle, and while the water is running out, the image is filling; but as soon as the bottle is empty, the illusion ceases. If the bottle likewise be quite full,

there is no illusion. The remarkable circumstances in this experiment are, 1. Not only to see an object where it is not, but also where its image is not. 2. That of two objects which are really in the same place, as the surface of the bottle and the water it contains, the one is seen in one place, the other in another, &c. It is supposed, that this illusion arises partly from our not being accustomed to see water suspended in a bottle with the neck downward, and partly from the resemblance there is between the colour of air and the water.

As parallel rays which fall on a concave mirror are reflected so as to unite at a focus; and as the sun is so remote, that the rays of each beam may be considered as parallel, they will converge to the principal focus of the mirror, and the heat produced by this means will be sufficient to set fire to such bodies as are placed before the mirror at the principal focal distance, that is, half a semi-diameter of the mirror's concavity. The different degrees of heat at the focus of different concave mirrors, is estimated in the same manner as we have already estimated the power at the focus of a convex lens.

The ancients made use of concave mirrors to rekindle the Vestal fires. *Plutarch*, in his life of *Numa*, says that the instruments used for this purpose, were dishes, which were placed opposite to the sun, and the combustible matter placed in the center; by which, it is probable, he meant the focus, conceiving that to be at the center of the mirror's concavity.

You have, no doubt, long since perceived that there is a great resemblance between the properties of convex lenses and concave mirrors. Convex lenses and concave mirrors form an inverted focal image of any remote object by the convergence of the pencil of rays.

Concave lenses and convex mirrors have also considerable resemblance in their properties; they in general form an erect image in the virtual focus, by the divergence of the pencil of rays.

In those instruments, as telescopes, whose performances are the effects of reflexion, the concave mirror is substituted in the place of the convex lens, and the convex mirror may be used instead of the concave lens; but their dispositions with respect to each other must necessarily differ from those of lenses, on account of the opacity of the one, and the transparency of the other.

The following curious experiments by Mr. *King*,* are too important to be passed over; besides which, they have an intimate relation to some of the subjects already treated of. He placed a common size candle at the distance of six feet from a concave glass mirror, two feet and an half in diameter; and at the distance of seventeen feet three inches, he placed a second glass mirror, two feet diameter; and in the focus of this glass, at two feet six inches, he placed the bulb of a thermometer graduated with *Fahrenheit*'s scale. In five minutes, the quicksilver in the thermometer, though at twenty-five feet, nine inches from the candle, rose eight degrees, namely, from 60 to 68; on being removed from the focus, it fell again to 60°. That its rise was not occasioned by any additional warmth in the room was certain, because another thermometer which was in the room did not rise at all in the interval. The alteration of the height of the quicksilver was therefore solely owing to the concentration and convergency of the rays of the light of the candle at the focus.

He then removed the candle, and, under the same circumstances, placed a little wire grate four inches in diameter, containing three pieces of lighted char-

* See Morsels of Criticism, by *E. King*, Esq.

coal, and causing them to burn bright by blowing a common pair of bellows, the thermometer was again placed in the focus; in six minutes it rose 19 degrees from 60 to 79, although the heat of the room was no way increased by the experiment, as it was very large. One remarkable circumstance attended this experiment, which was, that there was very sensibly to be perceived a small increase of heat the whole way from the surface of the second mirror to the focus; whereas, when the rays of the sun are made use of, no such increase of heat at all is ever perceived within the conical convergency.

After making several similar experiments, all of which concurred in proving that the effect was produced by the rays of light and heat from the ignited bodies, Mr. *King* placed a tea-urn of boiling water in the place of the charcoal, at the distance of six feet from the first mirror, and placing the thermometer in the focus of the second mirror, in the space of five minutes the quicksilver rose one degree, which was even more than could be expected; in the next five minutes, the thermometer advanced one degree more, and yet the other thermometer in the room remained stationary; in another five minutes, the steam cooling, the thermometer began to descend, and in five minutes more the quicksilver fell one degree.

The result of these experiments is clear and obvious: that fire is in a degree subject to the same kind of reflexibility and refrangibility with the rays of light; and from a convex lens being interposed between the mirror and the focus, augmenting the effect of the heat.

If a luminous body be placed in the focus of a concave mirror, its rays will be reflected in parallel lines, and will therefore strongly enlighten, at a great distance, a space of the same dimension with the mirror. If the luminous object be placed nearer

than the focus, its rays will diverge, and consequently enlighten a larger space. It is on this principle that reverberators are constructed.

But few articles on this subject remain to be discussed. I have only to shew you how to find the principal focus of these mirrors, and then give you a concise view of the properties we have already investigated, and an explanation of the various phenomena of pictures viewed in a concave speculum.

TO FIND THE FOCAL LENGTH OF A SPHERICAL SPECULUM.

1st. For a concave speculum. Place the speculum so that its axis may be nearly towards the center of the sun. If the speculum be concave, find the burning point, or receive the image upon a white piece of paper; and the distance between the focus so found, and the vertex of the speculum, is the focal length. Or, cover the speculum with a sheet of opake paper, in which make two or more holes, and observe where the beams of light reflected from these holes unite, and this will be the focal distance. Or, lastly, place the speculum at the end of a long table, in a vertical position; place a candle at the opposite end of the table, so that its flame may be opposite to the vertex of the speculum; then take a piece of white paper, and, having fixed it to a stick, place the stick in the socket of a candlestick, so that the paper may be supported at about the same height with the candle; then move the paper or the candle forwards and backwards, till the image of the candle on the paper is exactly over the candle itself, and the point of coincidence is the center of the speculum.

2dly. For a convex speculum. Stick two round opake patches thereon, and hold a white paper parallel to the speculum, and observe where the shades

of the patches fall upon it, as at G, H, *plate* 6, *fig.* 1; measure exactly the distance AG, and the distance betwixt the centers of the shades G, H, and between the centers of the patches AD; then as GH−AD (=eH) to AD, so is AG (=De) to AF, the distance required.

Or, cover it with paper, having two pin holes made, one near each edge of the mirror; expose it to the sun, holding another paper before it, having a hole large enough to let the solar rays pass through to the two pin holes. You will see two white spots of reflected light on each side the hole; move the paper backward and forward, till the distance of the spots be twice the distance of the holes in the cover, and that distance of the paper from the mirror is the principal focus.

GENERAL PROPERTIES OF SPECULUMS.

To see the image of an object made by any spherical speculum, the eye must be placed in the diverging rays, facing the image, and at a proper distance for distinct vision.

If the eye be placed near the speculum, in the converging rays before they reach the image, it will perceive the image of the object beyond the glass, and at the same distance nearly as the object is before it, and of the same magnitude.

If both eyes, in order to view an image, be placed near to the point in the diverging rays, where it is to be represented, it will either not be seen, or it will appear double; for the axes of the eyes cannot both be directed to an object extremely near.

Though an eye cannot see an image in the air, except it be placed in the diverging rays; yet, if that image be received on a white paper, it may be seen in any position of the eye. For the rays reflected from the mirror to the image and beyond, flow but

in that direction; but when the image is received on white paper, the rays are reflected in every direction.

If the eye be moved whilst it views the image, the image will appear to be moved; for rays will come successively to the eye from different points of the speculum.

If an object be placed in the principal focus of a concave speculum, its apparent magnitude to the eye, at any place whatsoever, will be invariably the same, and equal to the apparent magnitude to the naked eye, when seen from the center of the speculum. Consequently, the apparent magnitude of an object, placed in the principal focus, will always continue the same, however the eye is moved backward or forward from the speculum.

The nearer the eye is to the speculum, the more of the object appears, and *vice versa*.

If the object be nearer than the principal focus, its apparent magnitude grows less in going from the speculum; if it be further off, it increases.

The apparent magnitude of an object will be invariable wherever it be placed, if the eye be at the principal focus.

When the eye is at a less distance than the principal focus, the magnitude of the object decreases as it is moved from the speculum.

When the eye is fixed at a greater distance than this focus, the apparent magnitude of an object increases in going from the speculum till it arrives at the conjugate focus; then it is all confusion. Afterwards it diminishes again, and is inverted.

A face in going from a concave decreases to the principal focus, and then increases.

OF PICTURES SEEN IN A CONCAVE SPECULUM.

If a picture, drawn according to the rules of perspective, be placed before a concave speculum, a little nearer than its principal focus, the image of the picture will appear extremely natural, and very nearly like the real one from whence it was taken. For not only the objects are greatly magnified, so as to approach nearer their natural size; but they have also different apparent distances, insomuch, that a view of the inside of a church appears very like a real church; and landscape pictures as the real objects would do, seen from the spot where the view was taken.

This curious phenomenon will be in a great measure accounted for, by attending to this diagram, *plate* 6, *fig*. 3. Where the curve, p q *r*, is the geometrical image of the straight object P Q R, or that curve which contains the foci of all the pencils of light that diverge from P R, and whose axes pass through the center, O, of the speculum B A C, after their reflexion by that speculum. Now it is proved by geometry, that the geometrical image of a circle facing the speculum, and whose center is at Q, and whose diameter is P R, will be a hollow figure, formed by the rotation of the curve p q *r*, round the axis O q. If this hollow figure is supposed to be a real thing, whose inside surface is variously distinguished into parts by different colours, and a picture of it be drawn upon the circle P R, the point of sight being at O; a spectator placed at O, would be affected much in the same manner, by rays coming to him from the picture, after reflexion from the speculum, as he would by rays coming to him directly from the hollow figure, the speculum and the picture being removed; for, in this case, the hollow figure,

and the geometrical image of the picture upon the circle, are both coincident.

Again, the geometrical image of a rectangular parallelogram A B, *plate* 6, *fig*. 4, placed where P Q R is, *fig*. 3, will be also a hollow figure; but more like a pyramid with four sides, than to the figure described by the rotation of the curve p q *r*. In like manner, a lesser parallelogram within the former will have the image of its sides like those of the former, but at a greater distance; and so likewise the sides of the several parallelograms, c d, e f, &c. will have their images in a series one behind the other, the middlemost being farthest of all; so that the geometrical image of the whole figure does somewhat resemble the frustrum of a hollow pyramid with four sides, and which, on account of the greater apparent distance of the smaller or middle parts, appear nearly like a hollow prism, a section of which is p s t *r*, of *fig*. 3.

Now if p *s*, or *r t*, be the length, and *s t*, or p r, the breadth of the inside of a church, a perspective view of which, from O, is drawn upon the plane P R, the geometrical figure will not be very unlike the church itself. For the picture upon the plane P R, is a figure properly consisting of several parallelograms diminishing towards the middle, after the manner of those above described; and if the picture be not too large in proportion to the size of the speculum, the curvities arising from the form of the speculum will not be very considerable. But as most of the pencils of light entering the eye, diverge from points that are at great distances, their different divergences are not alone sufficient for determining the true place of their foci: and the apparent image of a blank surface placed at P R, will not appear near so concave as the geometrical image.

Here, however, we must have recourse to some other cause, and we shall find many concurring ones. The contiguous parts of the picture of the floor, for instance, form a long series of visible images, contiguous likewise to one another. The images of the remoter parts appear also at the same time fainter and smaller, because the pictures of the remoter parts of the real floor diminish faster in proportion than the apparent distances of the images of the picture increase; so that from all these causes conspiring together, the eye receives much the same impression as if it looked at a real floor; in both cases, the appearance is much the same; a long extended surface, a little diminished in breadth, and that gradually towards the farther end. In like manner the walls appear erect and extended on each side, and the roof above facing the pavement; and all gradually inclining, after the same manner as a large room appears to the naked sight when viewed from one end. Besides the above helps, the window light in the sides, the shades of upright objects thrown upon the pavement, &c. in the pictures, do all contribute their share; and all conspiring together, do sufficiently outweigh the imperfections of the geometrical image. So that, instead of a distorted picture, we see in a manner a real church; the great magnitude of the whole, its visible concavity, and proportionable length and distance of parts, all contributing powerfully to excite this idea. Landscapes, &c. are in like manner strikingly improved by a concave speculum.

These phenomena appear rather more perfect to both eyes than to one alone; and the appearance will be the same to one who does not know what the picture on the paper represents, which proves, that the said phenomena are not founded upon mere prejudice. A young child, who had never seen

any thing like what was represented, shews great marks of joy and surprize upon looking at a print in a concave speculum. If it can be said that nature is any where improved upon, I think this is the place: for if the print or picture be finely executed, the opportunity we have of viewing its image, without any extraneous light intruding into the eye, is an advantage we cannot have when we look at remote objects, and is productive of a wonderful effect.

OF VISION, BY LIGHT REFLECTED AT A CONVEX SPECULUM.

We have very little to add to what we have already said on this subject. In a convex speculum, the images of objects are always seen erect, a little convexed towards the eye, and diminished, yet rather near to the speculum; and the greater the convexity, the nearer, the smaller, and the more convex will the images of objects be.

If the speculum be a pretty large segment, it will exhibit the images of the objects that are pretty wide asunder; so that part of the cieling, floor, and two sides of the room, may be seen at the same time, the whole making a kind of picture very agreeable in its effect: and the nearer the eye is to the speculum, the larger will be the field of the visible images. The appearance is a kind of mean between the objects themselves and a good picture of them on a flat surface; and upon this account, and also for grouping the objects, a convex speculum may be very useful to a landscape painter, by whom one ground from a black sort of glass, is the most esteemed, as it gives but one true shade to the objects represented. A convex mirror is now fashionably a part of furniture in every drawing-room, as it presents the owner with a pleasing scenography of

the interior parts of a room, all its furniture, and all the company in whatsoever manner assembled.

If, while the objects and speculum remain fixed, you move to or from the speculum, the apparent places and magnitude of the images will remain invariable: but if an object moves to or from the speculum, its image will also appear to move the contrary way; and as it approaches nearer or recedes farther, it will appear more and more enlarged or diminished.

If a convex mirror be placed opposite a window, having an extensive prospect, or facing the end of a street, the great multiplicity of objects that are seen one beyond the other, and the diminution of their images, will sometimes, after looking on the speculum, make us fancy they are at a great distance; and, perhaps, further than the objects themselves. But, on a more attentive view, this mistake will be corrected, and the apparent places of the images will not differ sensibly from their real places, or those places whence the rays diverge to the eye.

OF VISION BY PLANE SPECULUMS.

We have already explained to you the abstract theory of images formed by the reflexion and refraction of plane and spherical mirrors; I shall now consider the phenomena of vision by plane mirrors.

Objects, as we have observed, seen by reflexion from plane speculums, generally appear so perfect and natural, that if the speculum itself is not perceived, we are liable to mistake the images for the real objects of which they are the types. A man appears alive, corporeal, and not a mere surface; and any series of objects placed before the speculum exhibit a like series on the other side, all appearing in their due places, agreeable to the theory of images and of vision; with this difference, that the images appear

somewhat darker than the objects, on account of the loss of light by reflexion; and this, when the images are remote, will affect their apparent distances; and more especially if, as the case often is, part of the floor sustaining the real objects is not seen, or if the speculum is not vertical. But when the images are near, these causes have no sensible effect.

When you see your own image, or that of an object behind you, in the speculum, if the image be erect, it will appear inverted as to right and left; and the reason is, because the object and the image face each other, or look contrariwise. The case is not unlike, when the object is between us and the speculum, though we are apt to make it different for want of considering, that it is the back of that towards us, and so call that the right side of the object, which we should call the left, if we were on the other side.

The phenomena of vision in plane speculums agree so well with the theory of images, that we need say nothing more on this head, but proceed to explain the phenomena, when two or more speculums are combined together, or when one is placed in an inclined situation.

If a plane mirror be inclined to the horizon in an angle of 45 degrees, with its face downwards, an upright object will have its image in an horizontal position, and the image of an object lying horizontal will be erect.

If AB, *plate* 6, *fig*. 6, be a plane looking-glass, with its reflecting surface downwards, and CD be an object parallel to the horizon, then the mirror AB, which makes half a right angle will make half a right angle with the object; or ABC will be an angle of 45°. Now, at whatever distance a point C, in the object is from the mirror, the correspondent c, in the image will appear at the same distance from the mirror on the other side; therefore CE will be

equal to c E: for the same reason any other point, D, will be just as far distant before the mirror as its correspondent point, d, is behind it; so that as the object forms an angle of 45° on one side of the mirror, the image will form also an angle, from the same angular point, of 45° on the other, 45 added to 45 making 90°, or a right angle, so that the image is perpendicular to the object, being therefore perpendicular to the horizon, will appear erect. For the same reason, an upright object will have its image in an horizontal position; consequently, if you stand upright before a mirror inclined to the horizon, the face upwards, you will see your image extended horizontally, as it were, on the floor, with your face upwards.

Hence, if you look into a plane speculum, inclined to the horizon in an angle of 45°, but with the face downwards, you will see yourself as it were in a flying posture; you will seem to be suspended horizontally in the air with your face downwards; and if the speculum is sufficiently long, you will seem to fly upwards or downwards, as you walk to or from the speculum.

If the speculum be inclined in any other angle, the angle of the image will be varied in the same manner: these positions you may easily verify by means of a common dressing-glass, as the inclination thereof may be altered at pleasure.

On these principles is constructed an optical deception, which Dr. *Hooper* has named the *animated optic balls*. On a flat board a serpentine groove is formed in such manner, that if the board be inclined, and a small ivory ball be placed at the top of the uppermost groove, or conveyed up there by clockwork machinery, it will roll with the same velocity till it gets to the bottom. This board is placed in a box in which there is a looking-glass so inclined, that the board appears vertical, and the lower end

uppermost; consequently, the ball will seem to roll upwards.*

In any number of plane speculums, all lying in the same plane, there can be seen, from the same place, only one image of the same object. For let there be ever so many, they have only the effect of one mirror, and the object is seen by rays proceeding therefrom to the eye.

If an eye is at I, plate 6, fig. 7, *within the angle* A B C, *formed by two plane mirrors* A B, B C, *it will see as many images of an object* O, *placed also within this angle, as you can let fall perpendiculars successively on the mirror from the object and each of the images.*

1. Let fall the perpendicular O D, on the mirror B C; make N D equal to N O, and the point D will be the place of the image: for, if you draw I D from the eye, and from g, where it meets the mirror, draw g O, you will find the angle of incidence, O g N, equal to the angle B g I.

2. If from the point D, you let fall on the mirror A B, the perpendicular D *k*, and make k E = k D, the point E will, for the same reasons, be the place of the second image, whose object is D.

3. If from E you let fall on the mirror B C, a perpendicular E Q, and make Q F equal to E Q, F will be the place of the third image, of which E is the object.

4. If from F, a perpendicular is let fall on A B, it will pass beyond B to G, beyond the limits of the mirrors.

In the same manner you may shew, that there is in H, an image of the object O, seen by the ray I *h*, reflected by the incident ray O *h*; and a second in K, seen by the ray *c* I, reflected from *c t*, reflected from the incident ray O *t*, that there is a third in L, seen by the incident ray O *l*, reflected in *l a*, and then in

* See a more explicit description in the Appendix to this Lecture. EDIT.

a k, and afterwards in *k* I; and that there can be no more, because the perpendicular L M, from the last image, falls without the mirror.

From the figure you will see, that the first image is seen by one reflected ray; the second by two; the third by three; and so on.

The distance of each image from the eye is equal to its incident ray, added to the sum of its reflected ray.

The first image is brighter than the second, the second than the third, and so of the rest: for the intensity of light is continually diminished, a considerable quantity being lost at every reflexion.

The larger the angle formed by the mirrors, the fewer the number of images; for the cathetus of incidence, separate from each other by an angular motion, equal to that with which the mirrors are separated, and are consequently carried nearer and nearer to the angular, and fall successively beyond it; so that when the mirrors form a right angle, there can be but two images, and when it is very obtuse, there can be but one; which is the number of perpendiculars that can be let fall from the object or the images of the object on the two mirrors.

If the two mirrors are parallel, and infinitely extended, there would be an infinite number of images; but, as they go on, their distance is greater, and their brightness less; they therefore soon become insensible. So that if two plane mirrors be placed parallel to each other, there will be a series of images of the floor or space between them, indefinitely extended both ways; there being no other limitation of their number than what is caused by the decrease of light from the continued reflexions. If you stand between two such mirrors, you will see in that fronting you, the images both of your fore and back part repeated several times, but continually fainter the farther off.

On this principle are constructed a variety of ingenious recreations; particularly those that are termed *the boundless gallery, the magical mirrors*,* &c.

In a single plane mirror, that is made of thick glass quicksilvered, many images of any bright object, as a candle, may be seen.

The first surface of the glass being solid and polished, is itself a mirror, which sends back all the rays which do not traverse the glass, and thus forms a weak image of the object. By looking at a candle obliquely in a mirror, you will see very evidently, by its exhibiting a series of images, that the rays of light are reflected several times between its surfaces: the images, however, all decreasing in brightness, till at last the rays become too faint to exhibit an image. These are more distinguishable, the more obliquely they are viewed. This phenomenon proves very plainly, that light suffers a considerable diminution in its passage through glass.

If a plane mirror turns upon an axis, the angular motion of the images is double that of the mirror.

Let AB, *plate* 6, *fig.* 2, be a mirror, OE an incident ray, EF a reflected ray. Now, suppose the mirror to turn upon an axis at E, and to take the situation CD, then the incident, OE, will have GE for its reflected ray. Now, the angle FEG, which expresses the angular motion or quantity that the reflected ray has moved from its first situation FE, is double of AEC, the angular motion of the mirror. If, therefore, the mirror moves one quarter of a circle, the reflected ray moves a half circle: it is for this reason that the images of the sun, by a mirror, move so fast; and hence, also, the images thereof reflected by water, even nearly quiet, appear much agitated, particularly when received at some distance from the point of incidence.

* For a description of the figures representing these, see the Appendix to this Lecture. EDIT.

To judge of the goodness of plane mirrors. Having endeavoured to explain the principle of the phenomena of plane mirrors, I shall now proceed to such observations as may enable you to judge of their goodness. A speculum should be exactly figured and well polished. The goodness of the figure of a plane speculum is easily known, by observing if images seen in all positions, especially in very oblique ones, and from all parts of the speculum, appear exactly equal, and similar to the objects: that is, if the images, especially the remotest objects in the room, appear natural, without having any part of them distorted, the speculum has a good figure. The straight edges of the rails of wainscot are good objects for experiment. A plane must be exceedingly erroneous that will distort a face looking into it, because the rays being returned almost directly back to the eye, small aberrations cannot be sensible. But if two persons look at each other's image as obliquely as they can, they will soon perceive if the speculum be faulty.

It is extremely difficult to grind a true plane; and the difficulty of making a good looking-glass is still greater, because the two sides should be exactly parallel as well as flat. If the images of a candle seen very obliquely, and in different obliquities, and from all parts of the glass, do not always keep pretty nearly at equal distances one from another; it is a proof that the sides of the glass are neither flat nor parallel.

The better a speculum is polished, the brighter will be the images; that is, the eye will receive more light from it. The darker the colour of a glass speculum, the higher is the polish. Different glasses, though equally well polished, will not always appear equally dark; yet generally the above rule takes place, and the darkest is to be preferred.

APPENDIX TO LECTURE XVI.

BY THE EDITOR.

CONTAINING A DESCRIPTION OF THE MODERN AND MOST APPROVED CAMERA OBCURAS, AND SOME USEFUL AND ENTERTAINING MACHINES, DERIVED FROM THE PRINCIPLES OF DIOPTRICS AND CATOPTRICS.

Of the simple camera obscura.

A Camera obscura, very useful to painters, artists, &c. may be constructed by means of a single lens only. If landscapes or distinct objects are to be represented, a lens from about four to twelve feet focus may be used, according to the commodiousness of the room, and the dimensions of the picture desired, as described by our Author on the scioptic ball and socket, at page 196. But if the representation of figures, plaister or other models, pictures, &c. are desired, a lens from about nine to twelve inches in focus, and about two inches and an half in diameter, will be found best. It must be fixed into the ball and socket, or simply in the window-shutter or window-board of the darkened room, see A, *plate* 9, *fig.* 3. A small temporary wooden frame or stage, B, to the shutter, on which must be steadily fixed the figure or picture C, but in an inverted position. To suit lenses of different foci, the stage may be from about twelve to twenty-four inches in length.

A white paper screen, D, being brought by trial to a suitable distance within the darkened room, will

receive a very beautiful representation of the external objects, and from which the artist may readily copy, or trace the various outlines or minutiæ of the parts.

Strong coloured figures and paintings are represented to a greater advantage than weak coloured ones. If the strong day-light or sun illumines the object at C, and the room is well darkened, the images will be very strong and vivid. They will be larger in proportion to the distance of the screen, D, from the wall, and the nearness of the object C; the reason of which, from what our Author has previously given in Lecture XV. must be evident to the reader.

This method, though simple and somewhat inconvenient, is the most perfect of all the various camera obscuras; the effect being produced by only one refractive medium, gives the images with the least loss of light possible.

The aperture of the lens, C, need never exceed three inches, and must be occasionally diminished by stout paper or metallic rims, with different holes or apertures, to suit the various sizes of an object, and different degrees of the intensity of light. The artist by trial will, under some circumstances, find, that too much light may pass through the lens, and prove of injury, by confusing the appearance of the picture.

Instead of the paper screen D, a large plane glass, polished on one side, and with a fine rough ground on the other, may be used; on this the images will be exhibited with more brightness and effect than on the paper, but the tracing of them on the glass will be rather more difficult than on paper.

By means of a plane reflecting glass mirror, obliquely placed, as represented by the dotted lines E, the images may be reflected down upon a white-painted table, or one covered with white paper,

within the room, but they will not appear so bright or distinct, from the light being somewhat diminished by this reflexion.

OF THE REFLECTING CAMERA OBSCURA.

The inconvenience of preparing a darkened room for the lenses, screens, &c. has occasioned the suggestion, by ingenious persons, of more ready and portable sort of camera obscuras. The pocket one, where the images are formed on a plane rough glass, I have already described in a note to page 198. It is proper to add here the description of a portable machine, by means of which, images of all sorts of objects may be represented on white paper, and the eye and hand of the artist can most conveniently be employed in the observing and delineation of them. *Plate* 9, *fig.* 4, represents this instrument as open, its various parts put up and together for use. These parts, when shut up, are all contained in the mahogany box below, shaped neatly like a chest, or formed like a book, covered with calf leather, lettered, &c. The front and sides, when placed up and hooked together, are at the height of about two feet from the case E F G. There are two hinges to each of the sides, as shewn at P, and the front is fastened by hooks and rings, as shewn at *a b c*, as also are the sides hooked to the back O, which is only the lid of the chest raised upwards. The head, A B C D, is a separate piece, and is hooked on withinside at C D. It is about four inches square, and contains a true ground parallel glass mirror, L, silvered, with a proper convex lens in a cell underneath. This head is connected to a wooden square trunk, about twelve inches long, and having on one side a brass rack N. This trunk slides within an outer one C D, having a brass pinion, at M, fitted thereto, which, by acting upon the rack when turned by the hand, moves ac-

curately upwards or downwards the lens and mirror from or towards the bottom of the box E F G, below. This motion is necessary for adjusting the lens to its proper focal distance from the white paper placed within, at the bottom of the box, that the images of the external objects may be formed thereon with the greatest distinctness. In viewing these images, the face is to be applied close to a pierced opening, made for that purpose, in the front K, and for tracing on the paper the hand into the cloth sleeve at the bottom, in the front F G.

To shut up this machine, the head is taken off, the front and sides are unhooked; the head and front put inside the case, the sides are turned over them, and the lid, O, turned down upon them, and a wooden front, with lock and key, secures the whole. The dimensions of the chest, when thus closed, is about twenty-two inches long, fifteen inches broad, and four inches deep. There is one or more convex lenses of different foci in cells, that fit in under the mirror, instead of the one before mentioned, which are adapted to the representation of nearer objects, such as houses on the opposite side of a street, profiles of persons in a room, &c.

This sort of camera obscura gives the relative positions of the images of the objects perfectly in the direct and natural way, and not either inverted or inversely, as shewn by others. The light and shades, the names on houses and doors, &c. are all depicted exactly as they appear to the eye in the original.

Fig. 5 is a representation of a mahogany frame, containing a large convex lens and plane mirror, diagonally placed, for viewing of perspective prints or views. It is fitted to the top and sides of the camera, *fig.* 5, at C D, and is applied there instead of the head A B C D. In this case, all the lower part of the front, O, is to be taken away to admit the light

upon the prints, placed at the bottom of the box, E F G. Upon looking through the convex glass, *fig.* 5, the mirror will occasion the prints to appear in a vertical direction, and under a pleasing and magnified appearance. This apparatus is called the *diagonal head*, as being the essential part of common optical diagonal machines usually sold for viewing perspective prints. The parts are hooked together, but when done with, may be turned over and folded into a flat form, to pack into the box, E F G, *fig.* 4.

A mahogany framed head, with mirror and lenses suitable to the distance, from about six to nine feet, is sometimes made to be applied to the roof of the garret of a house or summer-house, commanding an extensive prospect. The head being contrived to turn all round an horizontal direction, see *fig.* 6. This instrument can, by any intelligent carpenter, be easily applied to the roof, to be put in and taken out occasionally. A round table, of about three feet in diameter, with a screw pillar to raise or depress its surface, for adjusting it properly according to the focal distance of the lens, or distances of the objects, will be necessary. Its surface should not be flat but curved to the segment of a sphere, according to the focus of the lens, and distance of the objects.

The representation of distant objects in this manner will afford the highest pleasure and entertainment to a select company; and if objects in motion, such as carriages, horses, ships, &c. favourably illuminated by the sun, present themselves, the picture will be formed in the most exquisite manner.

OF THE MOST CURIOUS OPTICAL MACHINES, PRODUCING VARIOUS ENTERTAINING DECEPTIONS OR ILLUSIONS.

Persons, unacquainted with the principles optics, have been surprized at the great illusion of their

sight, by an artificial construction of many optical instruments, exhibited by showmen and others. The general principles that our Author has explained in the two preceding Lectures are sufficient to account for the reason of the effects by the following machines: a bare description of their construction and uses will be only necessary to inform the reader of the method of exhibiting the experiments, and of the considerable entertainment they afford to any select company not very conversant in the science. And, that although the instruments may not to the philosopher be deemed interesting or useful, yet it may be remarked, that from such inferior articles have arisen discoveries of the greatest value and importance.

THE DIOPTRICAL PARADOX, OR OPTICAL DECEPTION.

Plate 9, *fig.* 7, is a representation of the dioptrical paradox. It consists of a mahogany base, ABCD, about eight inches square, with a groove, in which slides various coloured prints, or ornamental drawings; a pillar, E, and horizontal bar, F, with a perspective G, are connected to the base. The perspective is placed exactly over the center of the base, and contains a particular formed glass hereafter to be described. The very curious and surprizing effect of this instrument is, that an ace of diamonds, in the center of one of the drawings, when placed on the base, shall, through the perceptive G, be actually represented as the ace of clubs; a figure of a cat in another, seen as an owl; a letter A, as an O; and a variety of others equally astonishing.

The principle of this machine is truly simple, and is as follows: the glass in the tube G, which produces this change, is somewhat on the principle of the common multiplying glass, *fig.* 7, *plate* 3, and is

represented at *fig.* 9. The only difference is, that its sides are flat, and from its base, hexagonally divided, diverge upwards to a point in the axis of the glass, like a cone, each side forming an isoccles triangle. Besides its figure, its distance from the eye is so adjusted, that each angular side, by its refractive power on the rays of light coming from the border of the print, and such a portion designedly there placed, will refract to the eye the various parts as one entire figure that is to be represented; the figure of the glass preventing any appearance of the original figure in the center, such as the ace of diamonds, being seen; consequently, the ace of clubs being previously and mechanically drawn in the circle of refraction, at six different parts of the border, 1, 2, 3, 4, 5, and 6, and artfully disguised therein by blending them with it, the glass in the tube, G, will change in appearance the ace of diamonds into the ace of clubs; and in like manner for the other prints.

As the refractive power of two different glasses are not precisely the same, this instrument is rather tedious in the making; for the inserting of the figures in the borders must, in every machine, be done by the hand on the print in the instrument, and observation through the perspective, G, at the same time.

Any number of changes may be designed and drawn, according to the skill of the draughtsman.

THE OPTICAL PARADOX.

Fig. 10 is a representation of the double perspective, or optical paradox. One of the perspectives of the instrument being placed before the eye, an object will be seen directly through both; a board, A, or other opake body being interposed, will not make the least obstruction to the rays; and the observer

will be surprized, as it were, that he sees through a perspective having the property of penetrating either solid metal or wood.

The construction of this instrument is chiefly from four small plane reflecting glass mirrors, *a*, *b*, *c*, *d*, *fig*. 11, of which *a* and *d* are placed at an angle of 45 degrees in the two perspectives, and *c* and *d* parallel thereto in the trunk below, which is so formed as to appear like a solid handle to the perspectives. It is evident, from the principle of catoptrics, that the object, J, falling on the first mirror, *d*, will be reflected down to *c*, on *b*, and up to *a*, and thence out to the eye, giving the appearance of the straight lineal direction, *a d*.

THE ENDLESS GALLERY.

Fig. 12 represents a mahogany or other box, about eighteen inches in length, twelve inches broad, and nine inches deep; but these dimensions are not essential, and may be altered at pleasure, except in about these proportions. In the inside of this box, and against each of its two opposite faces, A and B, place a plane true-ground glass mirror as free from veins as possible, of the dimensions nearly equal to the faces, only allowing a small space for a transparent paper, or other cover at top. From the middle of the mirror, C, placed at B, take off neatly a round surface of the silvering, about one inch and an half in diameter, where in the side of the box must be cut a correspondent hole not more in diameter than that of the glass. The top should be of glass covered with gauze, or of oil transparent paper, it being essential that as much light as possible be admitted into the box. Within this box on the two long sides must be cut or placed two grooves, at E and F, to receive various drawings or paintings, as hereafter described. It is best to cut many grooves in the

sides for the reception of such a variety of objects as may be desired. Two paintings or skilful drawings of any perspective subject must be made on the two opposite faces of a pasteboard, see *fig.* 13 and 14, such as forests, gardens, colannades, &c. After having cut the blank parts carefully out, place them in the two grooves, E and F, of the box. Paint also on two other boards of the same dimensions similar subjects, but only on one side, observing that the one which is to be placed on the glass, containing the opening C, should have nothing drawn there to prevent the sight, and that the other for the opposite side, D, should also not be very full of figures. After it is neatly cut out and placed on the glass, it should cover but a small part of it. The other board should be cut out, and also contain but few figures, so as only to be necessary to disguise the repetition of the aperture C, without which it would appear on the glass D; this is to be applied to the glass D. The top is then to be covered up with its transparent cover, and the instrument is ready for use.

The effect is very entertaining and striking. The eye being applied to the opening, C, will see the various objects drawn on the scenes reflected in a very successive and endless manner, by being reflected from one of the mirrors upon that which is opposite; as for instance, if they were trees, it would appear an entire grove, very long, and of which there would appear no end; each of the mirrors repeating the objects more faintly, as the reflexions are more numerous, and thereby contributing still more to the illusion.

Ingenuity will suggest a variety of entertaining figures of men women, &c. to increase the effect; and two mirrors may also be placed on the sides, to convey an idea of great breadth as well as length.

THE ANIMATED BALLS BY SIMPLE REFLEXION.

The machinery for this recreation being carefully constructed, will produce one of the most pleasing and entertaining amusements. I shall, therefore, give a more detailed description.

Procure a mahogany or other wood box, A B C D, *fig.* 15, *plate* 9, about two feet high, and fifteen inches wide, and towards the upper front part make an opening, E, of eight or nine inches in height, and seven or eight inches in width, and in this fix a true ground plane glass. The depth, B D, of the box, as represented in the profile of the figure, must be two feet, and a partition, S T, fixed in it, of the same width or fifteen inches; which will make an upper and under division in the box, and the latter be about one inch more than the former.

On the upper division, and near the extremity S, of the partition S T, place across it a small decoration, K S, of the figure of a front scene of a theatre, with an opening of about nine inches in height, and seven inches wide. Place behind this a true ground glass mirror, K F, inclined in an angle of about thirty or forty degrees at most, and it must be of the same width as the box, so as to be sufficiently large to cover the opening of the front scene, K S, when the eye is looking at it from E. Ornament the interior space, K S T B, with such drawings or paintings as will contribute to the elegance and pleasure of the exhibition; and cover the top of the box from K to B with a frame containing a glass ground with fine emery, or covered with a fine gauze, so as the light may be admitted as much as possible into the part K S T B. This being done, and with proper care, the next article to be placed is the inclined plane hereafter described,

and which must be of dimensions proper to enter by a door made in the back G H.

Construction of the inclined plane. This plane, I M, should be more or less extended and inclined on the base, C D, according to the greater or less inclination which is given to the mirror K F. The plane may be supported by two triangular props underneath placed at I M L.

On the upper surface of this plane must be painted or drawn a pleasing subject, such as a garden with flowers, or a piece of architecture, &c. in such a manner that it may appear regular when viewed from E, by reflexion from the inclined mirror above; and as some places may be perceived on the sides of the box, place horizontally towards K S decorations which may cover them.

Cut in this inclined plane a groove of abont three tenths of an inch deep, equally large throughout, and smoothly finished; this groove must be so disposed; that the ball, while descending, may make various windings as represented at I M, and at last, approaching the middle of its inferior side C D, disappear by going away into the groove or channel, O P, and falling into a box, H, made to receive it in the wheel-work hereafter described. Several ivory balls rather more than half an inch in diameter should be provided, which are to roll freely in the groove just described. It would be better to contrive the inclined plane, I M, so as to admit of being raised or depressed, to regulate the motion or velocity with which the ball should roll.

Inside of the box, about R, two small lamps or wax candles should be placed to illuminate the inclined plane, and no other part of the machine. If reflectors are placed behind, it would be better. A door must be made to admit these being taken out, a cover of tin, and a funnel for the conveyance of the smoke.

Construction of the apparatus for incessantly remounting the balls. This machine is similar to clock-work, and contains a barrel with a coiled spring, and wheel and pinions. There is no peculiar plan of the wheel-work; the following is such as recommended and described by Mr. *Guyot*. Provide a train of clock-work contained in a brass frame, E F G H, *fig.* 16, composed of a barrel with a spring and ratchet wheel and click, as in a common clock, fixed to the large wheel with teeth, A; a second wheel, B, the pinion of which is connected with the wheel, A; a third wheel, C, the pinion of which is turned by the wheel, B; and a fly, D, the pinion of which is turned by the wheel, C; the wings of this fly should be moveable, so that a quicker or slower motion can be given, as may be necessary. The axis of this wheel, B, should project about one-half an inch beyond the side of the frame, to receive the center of the brass arm, H I, *fig.* 17, which must carry at its two extremities two boxes open towards H and I, and enlarging towards the bottom. In the interior part of these boxes, should be fixed a small plate of brass moveable on a pivot, F, and bent towards E; so that, when one of the balls, having rolled down the inclined plane, shall pass into the bottom of one of the boxes, and, by its weight, shall elevate the other end of the arm H I, and raise it from its place where it was stopped, leaving by these means the branch at liberty to turn until its opposite end shall in its turn be stopped; so that the upper ball thus remounted shall roll out of its box into the upper part of the groove of the inclined plane; from whence descending again, a ball will disengage the second box; and so on alternately, until the spring contained in the barrel is uncoiled, which may be a number of times, in proportion to the number of the teeth in the wheels and pinions comprizing the wheel-work. The spring in the

barrel may be wound up by a key placed on its axis, as in common clock-work. It is necessary to add, that the action of one of the balls going into the box disengages at the instant the stop that prevents its motion at the time, after discharging the other at the top.

The following is the effect of this recreation. When a ball is put into the groove at top of the inclined plane, a person looking at it through the opening, E, *fig.* 15, will imagine that it ascends by various windings, contrary to the common gravity of bodies, and goes out at top of the edifice; which will appear more curious and pleasant, as the different windings are judiciously adapted to the subject painted on the plane.

To exhibit the same by a double reflexion. This apparatus differs from the foregoing, by only having a glass mirror inclined in an angle of 45 degrees, instead of the inclined plane, and by having that plane on which the balls roll placed in the part of the box, T D. There may, besides, be placed towards S T, and in a position almost horizontal, small columns, arbours, and other objects, made of brass wire, placed at equal distances, and joined together at the bottom by semicircles, which must be so contrived as not to obstruct the course of the ball.

If the room in the box will admit, under the former may be placed another similar arrangement of wires; so that the ball having rolled over the first, may descend to the other, which will produce a curious and striking effect, as the balls will seem to rencounter and pass over each other. There must, therefore, be two conductors for the balls; so that one ball may enter on one side, and the other on the opposite side. There should also be a third conductor, which, after the ball has passed over the third piece, may carry it to the top of the inclined plane

placed opposite to the second mirror, that it may pass down through all the windings.

The wire for the balls should have a small inclination about two lengths of an inch for a foot, and the distance of the wires something less than the diameter of the balls.

Small variations may be made in the ornaments, &c. to this machine, the balls coloured red or otherwise; the greatest effect being produced by an ingenious and perfect mechanical construction of its various parts.

THE REAL APPARITION.

Behind a partition, AB, *fig.* 18, place somewhat inclined a concave mirror EF, which must be at least ten inches in diameter, and its distance equal to three-fourths from its center. In the partition, cut a square or circular opening of seven or eight inches in diameter, directly opposite to the mirror. Behind this a strong light, such as from large candles or Argand's lamp, which must be so disposed that it may not be seen at the opening, and illuminate strongly an object placed at C, without giving light to the mirror. Beneath the aperture, place any object, C, that is intended to be represented on the outside of the partition, in an inverted position, which suppose a flower, figure, picture, &c. Before the partition and below the aperture, place a flower-pot, D, or other suitable pedestal, so as the top may be even with the bottom of the aperture, and that the eye placed at G may see the flower in the same position as if its stalk came out of the pot.

The space between the back part of the partition and the mirror must be painted black, to prevent any extraneous light being reflected on the mirror; in fact, the whole should be so disposed, as to be as little enlightened as possible, for the proper ma-

nagement of the light and shade is as material as any other part to the experiment; the strength and bold effect of the image depends entirely upon it, and for want of this precaution many attempts have failed, and the experiment ignorantly depreciated.

When a person is placed at G, he will perceive the flower or other object placed behind the partition; but, on putting forward his hand to pluck it, he will find that he attempts the grasping of a phantom.

Fig. 19 represents a different position of the mirror and partition, and better constructed for exhibiting effect by various objects at the instant. A is a thin partition of a room from the cieling down to about two feet and an half from the ground. B, a continuation of it, with an aperture for a good convex lens turned outwards into the room nearly in an horizontal direction, proper for viewing by the eye of a person standing upright from the floor or footstool. C, a continuation of the partition to the ground, so as to exclude every observation of the internal arrangement from the spectator at the outside. D is a large concave mirror supported at a proper angle, to reflect upwards through the glass in the partition B, images of objects at E, presented towards the mirror below. A strong light from lamps, &c. is to be directed upon the object and no where else; and, to the eye at E in a darkened room, it is truly surprizing and admirable to what effect the images are reflected up into the air at G. It is from this arrangement, that the showman mentioned by our author, page 230, is now exciting the ignorant distant from the metropolis to the surprize of wonderful apparitions of various kinds of objects, such as a relative's features for his own, paintings of portraits, plaster figures, flowers, fruit, sword, dagger, death's head, &c. and

all to produce a sudden effect upon the mind or imagination.

To cause the appearance of a flower from its ashes.

A concave mirror is here again the material article in the machine. *Fig.* 19, ABCDEF, represents a wooden box about two feet and an half high at AC, fifteen inches at DF, and, for the length, eighteen to twenty inches; and its breadth, DH, about twelve inches. In an opening made in the side, B E, place a glass bottle six inches in diameter, which fitting exactly the aperture, disguises the mirror, N. A paper circle, O, of six inches diameter, containing a bar magnet suspended by a fine thread for a center, underneath the part E G. Four small neat artificial flowers are to be fixed to the circumference of the card at equal distances, and so adjusted as by the mirror to be reflected in the bottle M. The inside of the box is to be made black, and by a door, P, a light introduced at Q, using all the necessary precautions for light and darkness as directed in the preceding experiments.

A small square box must be provided, about six inches square, having four compartments, and a corresponding magnetical bar concealed inside. In either of these four squares, the ashes of the burnt flower, similar to one of the four on the circle, is to be deposited, and the box placed at top, S, by a private mark made for that purpose, and in such a position, that the attraction of the magnet may bring the proper flower before the mirror N. A person then with his eye at some distance from the bottle M, will perceive, to his surprize, the flower in it that he was told had been burnt to ashes.

Any of the four ashes might be previously named, and the appearance of the flower restored in an instant. In the bottle may be placed clear water, and in the experiment, it may be said that it is a

particular prepared liquor that restored the flower from the ashes.

The phenomena to be produced by concave mirrors are endless; what have been just described, will illustrate those already noticed by our author, I shall conclude this appendix by describing one more machine, which, if properly constructed, will afford equal entertainment and surprize with the preceding.

THE OPTICAL PERSPECTIVE BOX.

Fig. 21 represents a box containing a concave mirror at its end AC; the length may be from eighteen inches to two feet, and breadth and depth according to the diameter of the mirror used. At IL is introduced a blackened partition to hide the frame of the mirror, and the hole cut in it is large enough to admit the view of the object to be placed at BEFD. The top of the box should be covered close from A to I; the other part, IB, may be covered with glass lined with gauze or paper. An aperture for both eyes must be made above, at G, and under this may be placed drawings, paintings, &c. which either by night or day must be illuminated as strongly as possible. By this simple construction, a very beautiful and perspective view of the object will be had, and in a manner very pleasing and entertaining.

If a perspective view of a landscape, shipping, &c. be painted on three pieces of glass, and placed about an inch apart at the inside end of the box BF, and so much of the end of the box cut out as to admit the rays of the sun, or the light from wax candles placed in a tin box behind them, it will afford one of the most enchanting views that can be imagined; the picture will appear actually extended like nature, and all the various subjects under a relief

much more perfect and bold than to the common eye without the mirror.

In this apparatus, the more the mirror is darkened and secreted and the more the objects are illuminated, the still stronger will be the effect. Common perspective prints of buildings, &c. usually sold with the common diagonal print machines, when perforated at different parts, such as the windows, &c. and transparent coloured paper applied thereon, have also a very pleasing effect in the box, and give the appearance of illuminations by night.

THE CYLINDRICAL MIRROR.

A concave cylindrical mirror, which is a glass ground by the revolution of a cylindrical tool turning on its axis, produces two or three curious and entertaining effects. The face presented to one mounted in a square frame will appear in one direction elongated, or, in a vertical direction, deformed in an extraordinary manner. If the mirror be turned a quarter round, the face will be extended in a similar way, but horizontally. A finger placed to the right side of the nose, while the face is within the focus of the mirror, will appear as in a plane mirror; but if the face and finger together be carried backwards in the axis of the glass beyond the focus, the finger will in a singular manner appear on the reverse side, though every other part of the face appears unaltered. The cause is from the mirror having only a longitudinal focus, in one direction, and that in the cylindrical direction of its curve.

For a description of other articles of recreation, see Recreations by *Hooper*, and in French by *Guyot.*

LECTURE XVII.

ON THE NATURE OF VISION.

It has been my endeavour, in the preceding Lectures, to rescue Philosophy from the imputation she has long lain under of being dangerous to religion and piety. It was not uncommon formerly to suspect every one, who professed to pursue the light of nature, of unsoundness of principles, and of a secret design to undermine the belief of a Providence, and the being of a God. Nor can it be denied, that there has been ground for such a suspicion; for those who really had such evil designs, proceeded by attempting to explain the surrounding phenomena by the powers of nature, and thus endeavouring to confine the attention of mankind to them alone. But the state of natural philosophy is now altered; it is become an innocent, inoffensive science, a useful minister in the temple of the Lord.

In ancient times, nature was esteemed an original source of being, distinct from the Almighty; matter was thought to be possessed of a being which HE never gave it, and the elements to have their differences and qualities independent of HIM. These notions have long since been exploded, and God is acknowledged to be the creator of all things visible and invisible. It is now clear, that the abstract and sensible essences of nature receive their permanency, and her courses their stability, from the covenant or immutable will of God; her substances, both material and spiritual, together with their primary as well as secondary qualities, their applications to one another, their mutual affections, and all effects and events resulting therefrom, being

derived primarily from no other source, than the power, the wisdom, and the goodness of God. Nature is the work of God, her acts are his, her productions his gifts, her every operation an execution of his will. "Great then is the error of those, who have set up nature as a first principle, in the place of God, whereby to account for physical operations and productions; for nature is nothing in itself, but a mere word without any meaning or idea belonging to it, if considered in any other view than as that system of laws whereby God upholds this visible world, and produces the infinite variety of forms and effects in it, according to an established and regular course of subordinate causes and means; and, consequently, where the mind terminates its views in a supposed nature as a self-moving agent or principle, it robs God of the honour due to his majesty, and transfers it to an idol of its own making."

The study of the human frame, &c. has been regarded with the same unfavourable suspicion as philosophy. For there being a great deal of mechanism in the human composition, those who applied to a close examination and study of the machine, were apt to think too slightly of the spiritual part, insomuch, that it has been a current saying, wherever you see three physicians, you see two atheists. But I do not apprehend that they now retain the same sentiments. They erred, because they saw that the understanding might sometimes be restored to madmen by medicines: they knew, that some of their drugs had a powerful effect upon the imagination, so as to warm it with sanguine hope, or chill it with desponding melancholy: they found, that a delicacy of texture in the fibres of the brain, a purity of the circulating juices, had an influence on the natural talents, and occasioned a predominancy of some one of the principal humours that distinguished the cha-

racters of men; that an unnatural pressure, or a little heterogeneous mixture in the medullary substance within the head, disabled the soul from exercising her functions; and that in general the tenour and colour of our thoughts depended very much upon the disposition of the body. Arguing from appearances, which will ever mislead, they imagined that powers had been ascribed to the soul, which really resided in the body, and were tempted in an evil hour too hastily to conclude, that she had none belonging to her; but that thought itself, with all its varieties, were nothing more than mere configuration and a diversity of motions in matter.

"Beginning at the wrong end, and tracing the intellectual operations from organized matter as their source and cause; they could not but infer, that the cause being taken away, the effect must necessarily cease. Seeing that a contusion, or other injury of the brain, occasions a disorder or loss of the understanding and memory, they thence argued that the brain is the principal cause or foundation of these powers; whereas, perception, thought, and memory, do not flow from the brain, but from the mind into it, as the proper medium for the manifestation of the intellectual powers. The defect or destrucion of the organ does not occasion any absolute loss or annihilation of intellect, for that still remains the same in its own spiritual principle, it only hinders it from manifesting its operations in the natural world." To suppose that mind and matter are the same, because the disorder of the body apparently influences the soul, is as absurd as to say that the art, science, and intelligence of a musician lies entirely in the strings or pipes of his instrument, because his knowledge is more or less conspicuous, according as they are more or less tuned. It is a sophistry that can only dazzle superficial minds, that thus takes appearances for realities, effects for causes.

But this temptation is now removed; for a more exact scrutiny into the properties of matter has clearly shewn, that no assortment of matter, how nicely soever arranged, can form an intelligent being. Let materialists insist as strongly as they please, that the characters and thoughts of men result from their machinery and organization; we know, that no such result can take place, unless there were a perceptive spirit to receive the action of the machine. To imagine otherwise would be as absurd as to suppose that a Bible might teach a sentiment of religion without a reader to peruse it; or the grass a sensation of green, without an eye to discern it. Some things indeed, the mind performs through the body; as for example, the various works and energies of art. Others it performs without such a medium, as when it thinks, and reasons, and concludes. Now, though the mind, in either case, may be called the principal source, yet these last are most properly its own peculiar acts, as more immediately referable to its peculiar powers; and thus is mind ultimately the cause of all.

"The ancient atheists, as *Anaximander*, *Democritus*, &c. founded their tenets on the hypothesis of matter being the first and only principle, to the exclusion of all spiritual substances. Their followers in infidelity, in modern times, have done the same: nor, indeed, is there any other supposition, weak as it is, on which the system of atheism can be raised."

"That the absurdities of a doctrine, which banished all wise designs and final causes from the creation and government of the world, might not, by unsupported assertions, shock the common sense of mankind, the authors and abettors of this impious scheme employed their invention to form theories to account for effects without causes, or, at least, with-

out adequate causes; as by maintaining the eternity of the world in its present form; or advancing, at least, an eternity of atoms, which, by the direction of chance, and a lucky jumble, formed themselves into the present orderly system."

"But as they were equally puzzled to account for life, consciousness, and intellect, upon their corpuscular plan, they found themselves under the necessity of ascribing to matter, under particular modifications, certain active powers, which are absolutely inconsistent with its known essential properties, affirming the soul to be nothing more than a mere refined and delicate configuration of atoms, and the mental operations to proceed from the mechanical motions of rarefied matter: thus making the principles of life and understanding to be only the modes of that which has nothing vital or intelligent in it, and thus ascribing more to the effect than is in the cause to give. These complicated absurdities have been so thoroughly detected and confuted, that atheism, as a system, scarce lifts up its head, but hides itself under false colours. It does not now present itself as the open, but as the whited sepulchre; does not professedly declare war against the majesty and existence of Almighty God, but slily endeavours to undermine his attributes, and by false reasoning to invalidate the proofs of the immortality of the soul."

Some philosophers among the ancients, as well as among the moderns, imagined that man was nothing but mere matter; but matter so curiously organized, that the impression of external objects produces in it sensation, perception, remembrance, and all other mental operations. This foolish opinion could have no other origin than the constant connection the Author of nature hath established between certain impressions made upon our senses, and our perception of the objects by which the im

pression is made; from which they weakly inferred, that those impressions were the proper efficient causes of the corresponding perception.*

But no reasoning can be more fallacious than this; that because two things are always conjoined, one must be the cause of the other. Day and night have been joined in a constant succession since the beginning of the world: but who is so foolish as to conclude from this, that day is the cause of night, or night the cause of the following day? There is, indeed, nothing more ridiculous than to imagine, that any motion or modification of matter should produce thought, and render it capable of sensation and knowledge. For those things, which are inferior and secondary, can by no means be the principal or causes of the more excellent.

If any one should relate of a telescope, so exactly made as to have the power of seeing; of a whispering-gallery, that had the power of hearing; of a cabinet so nicely framed as to have the power of memory; or of a machine so delicate as to feel pain when it was touched; the relation would be so absurd, and so shocking to common sense, that it would not find belief even among savages. Yet it is the same absurdity to think, that the impressions of external objects upon the machine of our bodies, can be the real efficient cause of thought and perception. The most perfect organization is but a perfect arrangement of material elements, and gives but a new extrinsic relation of parts to parts, and can never give capacities which did not before exist. Nay, the very materialist himself, with all his boasted attachment to matter, is forced to have recourse to powers which are as different from the common capacities of body, as the sentient substance of the immaterialist is from the material element.

* See *Reid* on the Intellectual Powers of Man, p. 34.

Even the man of matter, when speaking of resistance in bodies, says, "that resistance is in most cases caused by something of a quite different nature from any thing material."*

It is no wonder that philosophers, whose ideas of mind and being are only derived from body and sensation, should be thus inconsistent; for they have a short method of explaining away the nature of truth. They reduce it to mere opinion, and consider it as a factitious thing which every man makes for himself; which comes and goes just as it is remembered or forgot; which, in the order of things, makes its appearance the last of any, being not only subsequent to sensible objects, but even to our sensations of them.

But there are other reasoners, who have had different notions; who represent truth not as the last, but the first of beings; who call it immutable, eternal, omnipresent. To these it must appear somewhat strange, how men should imagine, that a crude account of the method how they perceive truth, was to pass for an account of truth itself: as if to describe the road to London, could be called a description of that metropolis.

You are better learned than to consider truth as opinion: you know that it shines with unchangeable splendor, enlightening throughout the universe every possible subject susceptible of its benign influence. Passions, and other objects, may prevent indeed its efficacy, as clouds and vapours may obscure the sun; but itself neither admits diminution nor change, because the darkness only respects particular percipients. Among these, therefore, you must look for ignorance and error, and for that sub-

* For a confutation of materialism, see *Berrington*'s Letters on Materialism—Immaterialism Delineated—and *Harris*'s Hermes.

ordination of intelligence which is their natural consequence.

From all these considerations, you will, I hope, be persuaded to flee from materialism as from the plague. It is an opinion that is inimical to virtue, that darkens the prospects of futurity, unbinds the reins to vice, and is destructive of all true religion.

Having given you an account of the general theory of reflexion and refraction of light, I shall now proceed to the theory of vision. The subject is not only curious and entertaining in itself, but without it there is no accounting for several optical phenomena, or even understanding the theory of optical instruments, and the manner by which they extend so prodigiously the natural boundaries of vision. It is also presumed, that it can be no unpleasing speculation to obtain an idea of the secret mechanism by which the eye communicates so many diversified and animated perceptions to the soul, and by which we are enabled to discover, with so much ease and rapidity, every surrounding object.

In the structure of the eye you will find the most evident manifestations of exquisite art and design, every part elegantly framed, nicely adjusted, and commodiously placed, to answer in the most perfect manner every possible good purpose, and thus evince, that it is the work of unerring wisdom, prompted to action by infinite love.

So manifold are the blessings we derive from this organ, that the mind of man seems almost inadequate to the conception, and his pen to the description of them. While it forms our ideas of magnitude and distance, it annihilates space, by placing the nearest and most distant objects close together. To it we are indebted for the delightful sensations that arise from the proportion and variety of forms, the harmonious mixture of colours, and the graces of

beauty. It enables us to seek, to see, and to choose our food; to go here and there, as the calls of friendship, or the occasions of business require; to traverse the ocean, ransack the bowels of the earth, visit distant regions, accumulate wealth, and multiply knowledge. Assisted by it, we become acquainted with the works of the Creator, and can trace his wisdom, his power, and his goodness in the texture of plants, the mechanism of animals, and the glories of the heavens.

The value of this sense is heightened, when we consider the miseries attendant on the want of it; for among the numerous evils that afflict the human race, there is none more justly dreaded, nor more deeply deplored, than a deprivation of sight. It is to have one of the chief inlets of happiness cut off, to be shut up in perpetual darkness, to labour under ten thousand inconveniences, and to be exposed to continual dangers. How poignantly this loss was felt by our great poet is painfully evident from his own words:

> "With the year
> Seasons return; but not to me returns
> Day, or the sweet approach of ev'n or morn,
> Or sight of vernal bloom, or summer's rose,
> Or flocks, or herds, or human face divine;
> But cloud instead, and ever-during dark
> Surrounds me, from the cheerful rays of men
> Cut off, and for the book of knowledge fair,
> Presented with an universal blank
> Of Nature's works, to me expung'd and raz'd,
> And wisdom at one entrance quite shut out."

A SHORT DESCRIPTION OF THE EYE.*

In describing the eye, it is natural to consider, first, the external parts, then the internal, or those which are more immediately subservient to the purposes of vision.

The eye, as is well known, is situated below the forehead; it is placed in a bony cavity, called the orbit; the form is globular, it is composed of several coats and humours, and furnished with vessels properly adapted to its various functions.

The eye consists of several coats or teguments, which form a ball perfectly globular except on the fore part, which is a little more protuberant than the rest. Within this ball are included three different liquids or transparent substances, called humours.

The orbit of the eye is of a conical shape, but rather irregular in its dimensions; it is composed of seven bones, and lined with fat, which forms a soft bed for the eye to rest on, and facilitates its various motions. A considerable part of the bottom of the orbit is open for the admission and transmission of the nerves, veins, and arteries.

Those prominent arches of hair, which we term the eyebrows, defend the eyes from the light when it is too strong, and prevent their being incommoded by any substances that might slide down the forehead, and thence fall into the eyes. That the eyebrows may be more effectually useful, and form a perfect screen, they are furnished with muscles to draw them down, and corrugate them; and when we are walking in a dusty road, or when we are exposed to a dazzling light, we pull down the eye-

* What follows on this subject is extracted from my "Essay on Vision."

brows, and thereby shade the eye from the glare, and protect it from the dust. We may gather from hence, that those shades which encompass the forehead, and that project about three inches from it, are properly adapted to guard weak eyes from every offensive glare of light.

The prominency of the eyebrows gives a character to the face; and hence *Le Brun*, in his directions to a painter, with regard to the passions, places in them the principal force of expression. The eyebrows form a deep shade on the canvas, which relieves the other colours and features. A depression of the eyebrow is an indication of concern and grief: whilst an elevation thereof shews that the mind is either affected with joy, or enjoying the serene delights of tranquillity.

The eyelids, like two substantial curtains, protect and cover the eyes while we sleep; when we are awake, they diffuse, by their motion, a fluid over the eye, which cleans and polishes it, and thus renders it fitter for transmitting the rays of light.

Each eye is furnished with two lids, the one superior, the other inferior, joining at the two extremities, which are called *canthi*, or angles. Both eyelids are lined with a membrane, which also infolds as much of the globe of the eye as is called the white, and it prevents any dust, or other extraneous particles, from getting behind the eye into the orbit.

That the eyelids may shut with greater exactness, and not fall into wrinkles when they are elevated or depressed, each edge is stiffened by a cartilaginous arch. The eyelashes, like two pallisades of short hair, proceed from these cartilaginous edges, warning the eye of danger, protecting it from straggling motes, and warding off the wandering fly. They also intercept many rays proceeding from objects that

are above the axis of vision, and thereby render the images of other objects more distinct and lively: for, as in the camera obscura, the image is always brightest when no rays are allowed to enter, but those which form the picture. The eyelashes contribute their share in giving beauty to the face, to soften the outlines of the eyelids, and throw a mildness on the features.

Both the eyelids are moveable; but the upper one mostly so, the lower one moving but little, being rather obsequious to the motions of the adjacent parts, than moved by any particular forces of its own. The hairs of the eyelashes grow only to a certain length, and never need cutting: the points of the superior one are bent upwards, those of the lower eyelash downwards. Thus, whenever we can trace things to their final cause, we find them always marked with design, and can find no circumstance so minute, as to escape the attention of the Supreme Being.

From what has been said, we may perceive why the sight of those, whose eyelashes are black, is, in general, much stronger than those who have them fair or white; the black eyelashes are a better shade for the eye, and reflect no light from their inner side, to weaken and efface the picture on the retina. *Montaltus* gives an account of a young man, whose eyelashes and eyebrows were of an intense white, and his sight obscure during the day, but clear at night. This person was taken prisoner by the Moors, who dyed his eyelashes black, by which his sight was much strengthened: in course of time the dye was washed off, and his sight became weak again. Dr. *Russell*, in his natural history of Aleppo, says, that it is the custom among the Turkish women to black the inside of their eyelids, not only as an ornament, but as a means of strengthening the

sight. When the eyelashes are lost, a symptom which frequently follows a malignant small-pox, the sight is always considerably impaired.

By shutting the eyelids partially, we can exclude as much light as we please, and thus further defend the eyes from too strong a light, which every one's experience proves to be as injurious to them as more gross matter. Numerous are the melancholy instances on record, which confirm this truth: *Zenophon* relates, that many of his troops were blinded by the strong reflexion from the snow over which they were obliged to march. *Dionysius*, the tyrant of Sicily, among other means which he used to gratify his revenge, and satiate the cruelty of his temper, was accustomed to bring forth his miserable captives from the deep recesses of the darkest dungeons, into white and well-lighted rooms, that he might blind them by the sudden transition from one extreme to the other. Actuated by principles equally cruel, the Carthaginians cut off the eyelids of *Regulus*, and then exposed him to the bright rays of the sun, by which he was very soon blinded.

These facts make it clear that a protuberant eye is not so well calculated for vision, as one that is deep sunk in the head: neither extreme is indeed desirable; yet undoubtedly, of the two, that which is deep set is preferable, as affording the clearest sight, and being the least liable to injuries from external accidents.

Those animals which have hard crustaceous eyes, as the lobster, crab, &c. have no eyelids; whereas most brute animals have an additional one, called the nictitating membrane, which they draw over their eyes like a curtain, to wipe off whatever incommodes them.

The velocity with which the eyelids move is so great, that it does not in the least impede the sight. This curious circumstance may be illustrated by the

well-known phenomenon of a burning coal appearing like a ring of fire, when whirled round about with rapidity, in the circumference of a circle. Now, it is highly probable, that the sensation of the coal, in the several places of the circle, remains on the mind until it returns again to the same place. If, therefore, our eyelids take no longer time to pass and repass upon our eyes, than what the coal of fire takes to go round, the impression made by any object on the eye will suffer no sensible interruption from this motion.

To prevent the eyelids adhering together, they are supplied with a row of sebaceous glandules, which discharge a soft liniment, that mixes with, and is washed off with the tears.

The lachrymal gland is placed in the upper and outer part of the orbit. It is designed to furnish at all times water enough to keep the outer surface of the eye moist, and thus give the cornea a greater degree of pellucidity. In order that this liquor may be rightly disposed of, we frequently close the eyelids without being conscious of it.

At the inner corner of the eye, between the eyelids, stands a caruncle, whose office seems to be to keep that corner of the eye from being totally closed; so that any tears, &c. may flow from under the eyelids, when we sleep, into the *puncta lachrymalia*, which are little holes, one in each eyelid, near the corner, for carrying into the nose any superfluous tears.

The eye is furnished with six muscles, which spread their tendons far over the eye; by these it can be moved upwards and downwards to either side, and in every intermediate direction, and thus view surrounding objects without moving the head. To facilitate these motions, a great quantity of loose fat is placed all round the globe of the eye, between it and the orbit. Four of the muscles are

straight, and two oblique; of the four straight muscles, two are situated vertically opposite one another, and the other two horizontally. Each of the six has a proper name, according to its situation and office. I cannot pass over the muscles, without taking notice of a striking instance of design in the wise disposition of the parts. It is sometimes necessary to have an oblique motion of the eye, towards the nose, and there being no room on that side for muscles, a small bone is placed on the side of the nose, with a hole in it, to serve as a pulley, through which the tendon of a muscle passes to a convenient insertion, and thereby such an oblique motion is given to the eye, as would otherwise have been impossible.

The eyes are placed in the most eminent part of the body, near the brain, the seat of sensation. From their elevated situation, our prospect is enlarged, and the number of objects taken in at one view, increased; we command an ample horizon on earth, and a glorious hemisphere of the heavens.

Every part of the human frame affords indisputable proofs of the wisdom and beneficence of its Creator, because all are adapted to answer in the best manner the end for which they were formed. Thus the globular figure of the eye is the most commodious we can form any idea of, the best adapted for facilitating the various motions of the eye, for containing the humours within, and receiving the images from without.

Many are the advantages that are derived from our having two eyes, some that are known, others that are unknown; for the correspondence of the double parts in the human frame, and their relation to the two great faculties of the human mind, has not been sufficiently attended to by anatomists. By having two eyes, the sight is rendered stronger, and the vision more perfect; for as each eye looks

upon the same object, a more forcible impression is made, and a livelier conception formed by the mind.

The eyes together view an object in a different situation from what either of them apart would do, and enable us to perceive small distances accurately. Hence we find, that those who have lost the sight of one eye, are apt to make mistakes in the distances of objects, even within arm's length, that are easily avoided by those who see with both eyes. Such mistakes are principally seen in snuffing a candle, threading a needle, or in filling a tea-cup. This aptness to misjudge distances and situations is, however, gradually diminished by time and practice.

When an object is placed at a moderate distance, we see more of it by means of the two eyes, than we possibly could with one; the right eye seeing more of the right side, and the left eye more of its corresponding side. Thus by both eyes we see in some measure round an object: and it is this which assists in giving that bold relievo, which we see in nature, and which no painting, how exquisite soever, can attain to. The painter must be contented with shading on a flat surface; but the eyes, in observing natural objects, perceive not only the shading, but a part of the figure that lies behind those very shadings. The perception we have of distance with one eye, as was just now observed, is more uncertain, and more liable to deception, than that which we have by both; therefore, if the shading and relief be executed in the best manner, the picture may have almost the same appearance to one eye as the objects themselves would have, but it cannot have the same appearance to both. This is not the fault of the artist, but an imperfection in the art. To remove these defects, the connoisseurs in painting look at a picture with one eye through

a tube, which excludes the view of all other objects. If the aperture in the tube next the eye be small, we have no means left to judge of the distance but the light and colour, which are in the painter's power.*

An object seen with both eyes, appears a little brighter, or more luminous, than it does when seen with one alone, as will be evident by looking alternately with both eyes and with one only: and the difference of brightness will be still more manifest, if at the same time that a part of a flat object, of an uniform colour, is seen with both eyes, the light from the adjacent part is excluded from one of them; which may be done by applying a book to one side of the head, so that it may reach a little forwarder than the face. But although the difference of brightness, in the two cases, is very perceptible, yet it is not very considerable, nor is it easy to determine it accurately. Dr. *Jurin*, by a variety of experiments, concluded, that an object seen with both eyes, appeared only one thirteenth part brighter, than when seen with one alone.

Our eyes have an uniform or parallel motion, by which, when one is turned to the right or left, upwards or downwards, or straight forwards, the other always goes along with it in the same direction. When both eyes are open, we find them always turned the same way, as if both were acted upon by the same motive force. This phenomenon is the more singular, as the muscles which move the two eyes, and the nerves which serve the muscles, are entirely distinct and unconnected.

To account for and explain the cause of this motion, has puzzled the philosopher and embarrassed the anatomist: that it originates from the grand moving principle, or generating cause within us,

* *Reid's* Inquiry into the Human Mind.

the mind, there can be little doubt; but how the mind operates, to produce this effect, we are altogether ignorant. Some effectual purposes are no doubt answered by this motion, for nothing is created in vain. One is supposed to be that of seeing objects single that are viewed with both eyes; for there are two pictures formed of every object, one in each eye. Hence, if any of the muscles of one eye, either from spasm, paralysis, or any other cause, is restrained from following the motion of the other, every object will be seen double. The same effect is produced, if, while we are looking at any object, we alter the direction of one of our eyes, by pressing it aside by the finger; an experiment frequently made by children, who are generally delighted with any uncommon appearance.

Whatever may be the cause, the fact is certain, that the object is not multiplied as well as the organ, and appears but one, though seen with two eyes: another instance of the skill of the contriver of this noble organ, and the exquisite art he employed in the formation of it.

Having considered the principal external parts of the eye, and shewn that they are framed to protect this delicate organ, with a care strictly proportioned to its curious texture, and extensive usefulness; that it is fortified with strong bones, lodged in a deep receptacle, and guarded with a moveable cover; we now proceed to treat of the internal parts, or those which constitute the globe of the eye.

OF THE GLOBE OF THE EYE.

If the construction of the universe were not so evident a proof of the existence of a supremely wise and benevolent Creator, as to render particular arguments unnecessary, the structure of the eye might be offered as one, by no means the least; this

instance, among numberless others, demonstrating that the best performances of art are infinitely short of those which are continually produced by the Divine Mechanic.

The globe of the eye, or the organ of sight, may be defined in general as a kind of case consisting of several coats, containing three pellucid humours, which are so adjusted, that the rays proceeding from luminous objects, and admitted at a hole in the fore part of the eye, are brought to a focus on the back part of it, where they fall upon a soft pulpy substance, from whence the mind receives its intelligence of visible objects.

It is not to be expected, that any account given of the eye can be altogether accurate; for as it is impossible to examine all the parts of the eye whilst in a natural and living state, so it is also nearly impossible, when it is taken out of its socket, to preserve the figure of the parts entire; a circumstance which accounts for the disagreement we find among anatomists.

OF THE COATS OF THE EYE.

The eye is composed externally of three coats or teguments, one covering the other, and forming a ball perfectly globular, except at the fore part, which is a little more protuberant than the rest; within this ball are three different substances, called humours.

The first, or outer coat, is called the sclerotica; the second, or middle one, is called the choroides; the interior one is named the retina.

Sclerotica. Cornea. The exterior membrane, which incloses and covers the whole eye, is called sclerotica and cornea: it is, however, strictly speaking, but one and the same membrane, with different names appropriated to different parts; the

hinder and opake part being more generally denominated the sclerotica, the fore and transparent part the cornea.

The sclerotica is hard, elastic, of a white colour, resembling a kind of parchment; the hinder part is very thick and opake, but it grows gradually thinner at it advances towards the part where the white of the eye terminates. The fore part is thinner and transparent; it is also more protuberant and convex than the rest of the eye, appearing like a segment of a small sphere applied to a larger, and is called cornea from its transparency. The cornea is thick, strong, and insensible; its transparency is necessary for the free admission of the light. This membrane is composed of several plates, laid one over the other, replenished with a clear water, and pellucid vessels; these plates are more evidently distinct in the fore than the hinder part. The sclerotica is embraced on its outside by six muscles, by which the eye may be moved in any direction.

Choroides. Uvea. Iris. Under the sclerotica is a membrane, known by the name of the choroides; it is a soft and tender coat composed of innumerable vessels; it is concentric to the sclerotica, and adheres closely to it by a cellular substance, and many vessels. This membrane is outwardly of a brown colour, but inwardly of a more russet brown, almost black. Like the sclerotica, it is distinguished by two different names, the fore part being called the uvea, while the hinder part retains the name of the choroides.

The fore part commences at the place where the cornea begins: it here attaches itself more strongly to the sclerotica by a cellular substance, forming a kind of white narrow circular rim: the choroides separates at this place from the sclerotica, changes its direction, turning, or rather folding, directly inwards, towards the axis of the eye, cutting the

eye as it were transversely: in the middle of this part is a round hole, called the pupil, or sight of the eye: the pupil is not exactly in the middle of the iris; that is to say, the centers of the pupil and iris do not coincide, the former being a little nearer the nose than the latter.

This part, when it has changed its direction, is no longer called the choroides; but the anterior surface, which is of different colours, in different subjects, is called the iris; the posterior surface is called the uvea, from the black colour with which it is painted. The iris has a smooth velvet-like appearance, and seems to consist of small filaments regularly disposed, and directed towards the center of the pupil.

The eye is denominated blue, black, &c. according to the colour of the iris. The more general colours are the hazel and the blue, and very often both these colours are found in the same eye. It has been observed, that in general those, whose hair and complexion are light-coloured, have the iris blue or grey; and on the contrary, those, whose hair and complexion are dark, have the iris of a deep brown: whether this occasions any difference in the sense of vision, is not discoverable. Those eyes which are called black, when narrowly inspected, are only of a dark hazel colour, appearing black, because they are contrasted with the white of the eye. "The black and blue are the most beautiful colours, and give most fire and vivacity of expression to the eye. In black eyes there is more force and impetuosity; but the blue excell in sweetness and delicacy."

The pupil of the eye has no determinate size, being greater or smaller, according to the quantity of light that falls upon the eye. When the light is strong, or the visual object too luminous, we contract the pupil, in order to intercept a part of the

light, which would otherwise hurt or dazzle our eyes; but when the light is weak, we enlarge the pupil, that a greater quantity may enter the eye, and thus make a stronger impression upon it. This aperture dilates also for viewing distant objects, and becomes narrower for such as are near. The contraction of the pupil is a state of violence, effected by an exertion of the will: the dilatation is a remission of power, or rather an intermission of volition.* The latitude of contraction and dilatation of the pupil is very considerable; and it is very admirable, that while the pupil changes its magnitude it preserves its figure.

Anatomists are not agreed, whether the iris be composed of two sets of fibres, the orbicular and radial, or of either. *Haller* says, he could never discover the orbicular fibres, even with a microscope; the radial seem visible to the naked eye, and are sufficient to answer all the purposes required in the motion of the iris: when the pupil is contracted the radial fibres are straight, when it is dilated they are drawn into serpentine folds.

In children this aperture is more dilated than in grown persons. In elderly people it is still smaller than in adults, and has but little motion; hence it is, that those who begin to want spectacles are obliged to hold the candle between the eye and the paper they read, that the strong light of the candle may force their rigid pupils into such a state of contraction, as will enable them to see distinctly. Those who are short-sighted, have the pupils of their eyes, in general, very large; whereas

* Anatomists observe, that in animals of prey, both beasts and birds, the pupil is round as in man, which fits them to see every way; but in large animals, which feed on grass, the pupil is oblong horizontally, for taking in a large circular space of ground: the pupil in animals of the cat kind, which climb trees, and want to look upwards and downwards, is oblong vertically.

in those whose eyes are perfect, or long-sighted, they are smaller.

The whole of the choroides is opake, by which means no light is allowed to enter into the eye, but what passes through the pupil. To render this opacity more perfect, and the chamber of the eye still darker, the posterior surface of this membrane is covered all over with a black mucus, called the pigmentum nigrum. This pigment is thinnest upon the concave side of the choroides, near the retina, and on the fore side of the iris; but is thickest on the exterior side of the choroides, and the inner side of the uvea.

The circular edge of the choroides, at that part where it folds inwards to form the uvea, seems to be of a different substance from the rest of the membrane, being much harder, more dense, and of a white colour; it has been called by some writers the ciliary circle, because the ligamentum ciliare, of which we shall soon speak, arises from it.

Retina. The third and last membrane of the eye is called the retina, because it is spread like a net over the bottom of the eye; others derive the name from the resemblance of the net, which the gladiators called retiarii, employed to entangle their antagonists. It is the thinnest and least solid of the three coats, a fine expansion of the medullary part of the optic nerve. The convex side of it lines the choroides, the concave side covers the surface of the vitreous humour, terminating where the choroides folds inwards. It is an essential organ of vision; on it the images of objects are represented, and their picture formed. This membrane appears to be black in infants, not so black at the age of twenty, of a greyish colour about the thirtieth year, and in very old age almost white. The retina, however, is always transparent and colourless: any apparent changes, therefore, of its colour must depend

upon alterations of the pigmentum, which is seen through it.

Optic Nerve. Behind all the coats is situated the optic nerve, which passes out of the scull, through a small hole in the bottom of the orbit which contains the eye. It enters the orbit a little inflected, of a figure somewhat round, but compressed, and is inserted into the globe of the eye, not in the middle, but a little higher and nearer to the nose; an artery runs through the optic nerve, goes straight through the vitreous humour, and spreads itself on the membrane that covers the back part of the crystalline.

M. *Mariotte* has demonstrated, that our eyes are insensible at the place where the optic nerve enters; if, therefore, this nerve had been situated in the axis of the eye itself, then the middle part of every object would have been invisible, and where all things contribute to make us see best, we should not have seen at all; but it is wisely placed by the Divine Artist for this and other advantageous purposes, not in the middle, but, as we have already observed, a little higher and nearer to the nose.

OF THE HUMOURS OF THE EYE.

The coats of the eye, which invest and support each other, after the manner of an onion, or other bulbous root, include its humours, by which name are understood three substances, the one a solid, the second a soft body, and the third truly a liquor. These substances are of such forms and transparency, as not only to transmit readily the rays of light, but also to give them the position best adapted for the purposes of vision. They are clear like water, and do not tinge the object with any particular colour.

Aqueous Humour. The most fluid of the three humours is called the aqueous one, filling the great interstice between the cornea and the pupil, and also the small space extending from the uvea to the crystalline lens; it is thin and clear like water, though somewhat more spirituous and viscous; its quantity is so considerable, that it swells out the fore part of the eye into a protuberance very favourable to vision. The uvea swims in this fluid. It covers the fore part of the crystalline; that part of this humour, which lies before the uvea, communicates with that which is behind, by the hole which forms the pupil of the eye. It is included in a membrane, so tender, that it cannot be made visible, nor preserved, without the most concentrated lixivial fluid.

It has not been clearly ascertained whence this humour is derived; but its source must be plentiful; for if the coat containing it be so wounded that all the humour runs out, and the eye be kept closed for a season, the wound will heal, and the fluid be recruited.

The colour and consistence of this humour alters with age; it becomes thicker, cloudy, and less transparent, as we advance in years; which is one reason, among others, why many elderly people do not reap all that benefit from spectacles which they might naturally expect.

Crystalline. The second humour of the eye is the crystalline, which is as transparent as the purest crystal; and though less in quantity than the aqueous humour, yet it is of equal weight, being of a more dense and solid nature; in consistency it is somewhat like a hard jelly, growing softer from the middle outwards. Its form is that of a double convex lens, of unequal convexities, the most convex part being received into an equal concavity in the vitreous humour.

The crystalline is contained in a kind of case, or capsule, the fore part of which is very thick and elastic, the hinder part is thinner and softer. This capsule is suspended in its place by a muscle called ligamentum ciliare, which, together with the crystalline, divides the globe of the eye into two unequal portions; the first and smaller one contains the aqueous humour, the hinder and larger part the vitreous humour. The crystalline has no visible communication with its capsule, for as soon as this is opened, the humour within readily slips out; it is supposed by some, that a small quantity of water is effused about it.

The crystalline is placed so, that its axis corresponds with that of the pupil, and, consequently, it is not exactly in a vertical plane, dividing the eye into two equal parts, but somewhat nearer the nose. It is formed of concentric plates or scales, succeeding each other, and these scales are formed of fibres elegantly figured, and wound up in a stupendous manner; these are connected by cellular fibres, so as to form a tender cellular texture. Between these scales is a pellucid liquor, which in old age becomes of a yellow colour. The innermost scales lie closer together, and form at last a sort of nucleus, harder than the rest of the lens. *Leeuwenhoeck* has computed, that there are near two thousand laminæ, or scales, in one crystalline, and that each of these is made up of a single fibre, or fine thread, directing into several courses, and meeting in as many centers, and yet not interfering, or crossing each other.

The yellow colour, wherewith the crystalline is more and more tinged as we advance in years, must make all objects appear more and more tinged with that colour: nor does our being insensible of any change in the colour of objects, prove to us, that their colour continues the same; for, in order that we should

be sensible of this change, the tincture must not only be considerable, but it must happen on a sudden, as will be more fully explained hereafter. In the cataract it is opake; the seat of this disorder is in the crystalline lens.

Vitreous Humour. The vitreous is the third humour of the eye; it receives its name from its appearance, which is like that of melted glass. It is neither so hard as the crystalline, nor so liquid as the aqueous humour; it fills the greatest part of the eye, extending from the insertion of the optic nerve to the crystalline humour. It supports the retina, and keeps it at a proper distance for receiving and forming distinct images of objects.

The vitreous humour is contained in a very thin pellucid membrane, and concave at its fore part, to receive the crystalline; at this place its membrane divides into two, the one covering the cavity in which the crystalline lies, the other passing above, and covering the fore part of the crystalline, thus forming a kind of sheath for the crystalline. The fabric of the vitreous humour is cellular, the substance of it being divided by a very fine transparent membrane into cellules, or little membranous compartments, containing a very transparent liquor.

Ligamentum Ciliare. There is still one part to be described, which, though very delicate and small, is of great importance; it is called the ligamentum ciliare, because it is composed of small filaments, or fibres, not unlike the cilia, or eyelashes; these fibres arise from the inside of the choroides, all round the circular edge, where it joins the uvea; from whence they run upon the fore part of the vitreous humour, at that place where it divides to cover the crystalline; those fibres are at some distance from one another, but the interstices are filled up with a dark-coloured mucus, giving it the appearance of a black membrane.

OF THE FIGURE REPRESENTING THE EYE.

Plate 3, *fig*. 10, represents a section of the eye through the middle, by an horizontal plane passing through both eyes; the diameter of the figure is about twice the diameter of the human eye.

The outermost coat, which is called sclerotica, is represented by the space between the two exterior circles B F B; the more globular part, adjoining to the sclerotica at the points B B, represented by the space between the two circles at B A B, is the cornea.

The next coat under the sclerotica is a membrane of less firmness, represented by the two innermost circles of B F B, and called the choroides.

Adjoining to the choroides, at B B, is a flat membrane, called the uvea. *a a* is the pupil, being a small hole in the uvea, a little nearer the nose than the middle.

V, the optic nerve; the fibres of this nerve, after their entrance into the eye, spread themselves within over the choroides, forming a thin membrane, called the retina, and is represented in the figure by the thick shade contiguous to the circle B F B.

E E is the crystalline humour; it is suspended by a muscle B b b B, called the ligamentum ciliare. This muscle arises behind the uvea at B B; where the sclerotica and cornea join together at b b, it enters the capsula, and thence spreads over a great part of its anterior surface.

The aqueous humour occupies the space B A B b C b.

The larger space B b D b B F contains the vitreous humour.

The foregoing description, I presume, will be found sufficient to give a general idea of the con-

struction of this wonderful organ; for a fuller account I must refer you to the writers on anatomy. The preceding explanations must shew to every reader with what art and wisdom the eye has been constructed.

OF VISION.

The representation of objects upon a sheet of paper, by means of a lens placed at a hole in the window-shutter, is exceedingly similar to what happens to our eyes when we view objects. For vision, so far as our eyes are concerned, consists in nothing but such a refraction of the rays of light by the transparent skins and humours of the eye, as will form a distinct picture of the object upon the retina. For the structure of the eye plainly indicates, that in order to attain distinct vision, it is necessary that a certain quantity of rays from every visible point of an object should be united at the bottom of the eye, and that the points of union of the rays of the different pencils should be as distinct and separate as possible.

The eye is admirably contrived for effecting these purposes: all the rays coming from any visible point of an object, that can enter the pupil, are united closely together upon the retina, and thereby make a much more powerful and stronger impression than a single ray alone could do; to answer this purpose, the retina is placed at a proper distance behind the refracting surfaces, and each pencil of rays is refracted orderly into distinct foci, that the whole object may be distinctly seen at the same instant.

These effects are owing to the refraction of the rays of light; for if these rays were not so refracted, very few of them would strike upon the least sensible point of the visionary nerve, and the

rays from different objects, or from different parts of the same objects, would strike at the same place at once, and thus create an indistinctness equal to blindness.

When the light is weak or strong, the pupil is accordingly enlarged or contracted, for the admission of more or fewer rays, that the impressions on the retina may be rendered suitable to the respective cases.

As the crystalline humour is densest in the middle, it is highly probable that it is not equally refractive. This difference in density of the constituent parts of the crystalline is admirably contrived for correcting the aberration from its figure, as well as that from the cornea. The more remote rays of each pencil, by passing through a medium gradually diminishing in density from the middle towards the extremes, have their foci gradually lengthened, which correct the aberrations of the figure, that so they may unite nearer together. The concave figure of the retina is somewhat serviceable for the same purpose.

It is by no means easy to determine with accuracy the measure of refraction of the different humours of the eye; from such experiments as could be made, it has been found that the refractive powers of the aqueous and vitreous humours are much the same with common water, and that of the crystalline a little greater.

The cornea and aqueous humour being supposed to have the same refractive powers, all three may be considered as one dense medium, whose refractive surface is the cornea; and the crystalline humour may be considered as a convex lens, placed in a given position within the same medium. Whence the humours of the eye altogether make a kind of compound lens, whose effect in refracting rays, having a given focus of incidence, is easily found by the laws of optics.

I have constructed three models to explain the action of the rays of light upon the eye. These models are represented at *plate* 3, *fig.* 8 and 9, *plate* 4, *fig.* 10. The rays of light are here prepresented by silken strings of different colours; the globe of the eye, by a glass ball. *Plate* 3, *fig.* 8, is the natural perfect state of the eye. *Plate* 3, *fig.* 9, represents the rays falling short of the retina as in a short-sighted eye. *Plate* 4, *fig.* 10, exhibits the action of the rays in a long-sighted eye. Let P Q R, *plate* 3, *fig.* 8, be an object; then the pencils of light B P B, B Q B, B R B, from the points P Q R, are first refracted by the cornea, so as to belong to foci behind the eye; then by the anterior surface of the crystalline humour, they are again refracted towards foci nearer to the eye than before; and lastly, in going out of the crystalline into the vitreous humour, they are again refracted, so as to unite in the points, pqr. In like manner, the pencils of rays coming to the cornea from every physical point of the object PQR, are, by the different refracting surfaces of the eye, brought orderly to unite upon the retina, and there form as it were an image, pqr, of the object, but in an inverted position; the upper part of the object being painted upon the lower part of the retina, the right side of the object upon the left of the retina, and so of other parts. Thus the cavity of the eye is a kind of camera obscura, the cornea and crystalline making a sort of compound lens, whose aperture is limited by the breadth, *aa*, *fig.* 10, of the pupil. And that the parts of the eye are adapted to produce such an image may be proved by experiment: for, if the tunica sclerotica be taken away from the back of an eye newly taken out of the head of any animal, and this eye be placed in a hole made in the window-shutter of a darkened room, so that the bottom of the eye be towards you, a beauti-

ful, but inverted picture of external objects will be exhibited, painted in the most lively colours.

If the humours of the eye, by age, or any other cause, shrink and decay, the cornea and crystalline grow flatter than before; and the rays not being sufficiently bent, arrive at the retina before they are united in their focus, and meet in some place behind it, see *plate* 4, *fig*. 10, and therefore form an imperfect picture at the bottom of the eye, and exhibit the object in a confused and indistinct manner. This defect, of which we shall treat more particularly hereafter, is remedied by spectacles with convex glasses, which by increasing the refraction of the rays of light, cause then to converge more, and thus convene distinctly at the bottom of the eye.

On the other hand, if the eornea and crystalline be too convex, the rays unite before their arrival at the retina, see *plate* 3, *fig*. 9, and the image thereon is of course indistinct. This defect, like the preceding one, may be remedied by the use of glasses, though of a contrary figure; for here they must be concave, instead of convex: a lens of a proper concavity placed before the eye, will make the rays from the object diverge so much more than in their natural state, as will cause them to meet at the retina.

OF THE ARTIFICIAL EYE.

There are many experiments which prove the mechanical effect of vision; but none of them render it so evident as with the eye of an animal abovementioned: an eye of an ox newly killed shews it very elearly, and with very little trouble.

The optical effects of vision may be very pleasingly and satisfactorily illustrated by the instrument which is called an artificial eye, and which has been lately considerably improved by Mr. *Smith*.

The artificial eye is so constructed as not only to shew the optical effects of vision, but to give also a complete idea of its conformation. It is one of the most perfect and satisfactory instruments in a philosophical apparatus.

The part representing the globe of the eye, and containing the humours, is fixed in a socket where it may be moved in any direction. This socket is fixed to a screen to shade the eye, that the picture formed on the back part may be more distinct: the hole in the front of the screen is shaped and coloured so as to exhibit nearly the form of our eye.

Take the eye in your hand and turn it towards any bright object, at a moderate distance, and you will see a lively, beautiful, distinct, but inverted picture of the object before it, on the rough part of the glass representing the retina.

Unscrew the cover that confines the ball of the eye, and take it out that we may dissect it. The outermost coat represents the sclerotica, the more protuberant part is the cornea.

This being removed, you find a plano-convex lens representing the first chamber of the aqueous humour; under this is a flat piece of tortoiseshell, to represent the iris, with a hole in the middle for the pupil; this being removed, you find a plano-concave lens, forming the second chamber of the aqueous humour. Now take off the second coat, or the choroides, and you will find a small lens, whose sides are of unequal convexities, to represent the crystalline humour; underneath this, is a large glass of the shape E D E V, *plate* 3, *fig*. 10, occupying the rest of the globular space, and answering to the vitreous humour.

To represent the nature of vision in a long-sighted eye, I substitute a plano-convex lens for the first chamber of the aqueous humour, whose convexity is less than that we used before. Turn the eye in

this state towards a bright object, and you find the image thereof is very imperfect on the retina; but on applying a proper spectacle glass before the eye, you obtain a perfect image.

By substituting a more convex lens for the first chamber of the aqueous humour, we have a short-sighted eye, and an imperfect picture on the retina: by placing a proper concave lens before the eye, the rays are rendered less convergent, and made to unite at the retina, and there form a distinct image of the objects as before.*

OF THE INVERTED POSITION OF THE IMAGE.

If vision be owing to the picture on the retina, it may be asked, why the object appears in its natural upright position? how, when nature draws the picture the wrong way, her errors are so readily corrected?

If it were as easy a task to give a satisfactory explanation of this abstruse question, as it is to start objections to every system hitherto suggested, to account for the operations of the mind on the body, and the body on the mind, it would have been explained long ago.†

The difficulty would be still greater, if it was the picture we saw, and not the object; but the picture

* The structure of the eye, as far as relates to the optical effects, is best illustrated by the artificial eye in brass, described by our Author in his Essay on Vision. A model of an eye to represent the various anatomical parts, and exhibit its optical effects, requires an artist of no ordinary skill. Mr. *Smith*'s eye has much ingenuity, but not equal to one I once saw, made by an artist at Edinburgh of ivory and glass. It corresponded in the most exact manner possible to all the various muscles, coatings, and humours of the eye. EDIT.

† See on this subject *Reid* on the Mind, *Potterfield* on the Eye, *Hartley* on Man, *Bonnet*'s Essai Analytique sur l'Ame, *Berkley* on Vision, &c. &c.

is not seen at all, the eye can see no part of itself; the picture is the instrument, by means of which the object is perceived; but it is not perceived itself; the instrument neither perceives, compares, nor judges; these are powers peculiar to that psycological unity which we call the mind.

It is absolutely necessary, in considering this subject, to distinguish between the organ of perception and the being that perceives. A man cannot see the satellites of Jupiter, unless assisted by a telescope: does he therefore conclude from this, that it is the telescope that sees those satellites? By no means; the conclusion would be absurd: nor would it be less absurd to conclude, that it is the eye that sees: the eye is a natural organ of sight, but the natural organ sees as little as the artificial.

Our senses are instruments, so framed by the Author of our being, that they correspond with, or have a determined relation to, those qualities in objects which they are to manifest to us. It is thus with the eye; it is an instrument most admirably contrived for manifesting visible objects to the mind; for this purpose, it refracts the rays of light, and forms a picture upon the retina; but it neither sees the object nor the picture. The eye will refract the rays of light, and form the picture after it is taken out of the head, but no vision ensues. Even when it is in its proper place and perfectly sound, an obstruction in the optic nerve takes away vision, though the eye has performed all its functions.

We know, indeed, how the eye forms a picture of visible objects on the retina; but how this picture makes us see objects, we know not; and if experiment had not informed us that such a picture was necessary, we should have been entirely ignorant of it. The seat of sensation, wherever it is placed, does not appear to be passive in receiving images; the images are the occasion of its re-action, and

directing a ray from itself towards every object it perceives; and this action and re-action are reciprocal. Hence we often see objects when the eye is turned from them, and often do not see the object on which the eye is turned, if the attention be otherwise engaged.

The pictures upon the retina are, however, a mean of vision; for such as the picture is, or such as the action of the rays of light is on the retina, such is the appearance of the object in colour and figure, distinctness or indistinctness, brightness or faintness; but as we are totally ignorant of the mechanism of the mind, or of the organization of the mental eye, we cannot say how this effect operates, and can only conclude, that the natural eye is an instrument of vision.

It appears very clear from Dr. *Darwin*'s experiments, that the retina is often in an active state, and that upon the activity of this organ many of the phenomena of vision depend; an impression on the retina being first made by an active power, which produces a conformable change and re-action, that passes directly to the sensorium, occasioning, though in an unknown manner, the perception of objects.

On a subject, therefore, confessedly so obscure, and which is perhaps beyond the limits of human conception in its present state, every explanation must be imperfect, every illustration inadequate. Among the various attempts of human sagacity to shew, why an inverted image is the mean of exhibiting objects to the mind in an upright position, the following is, perhaps, one of the least imperfect.

Every point of an object is seen in the direction of a right line, passing from the picture of that point on the retina, through the center of the eye, to the object point; and therefore such points indicate to the mind the existence of the object point, and its true situation; and of course, that the object, whose

picture is lowest on the retina, must be seen in the highest direction from the eye; and that object, whose picture is on the right of the retina, must be seen on the left: so that, by a natural law of our constitution, we see objects erect by inverted images, and if the pictures had been erect on the retina, we should have seen the object inverted.*

But, supposing the preceding illustration to be the true one, and quite satisfactory, many difficulties still remain to perplex the philosopher and embarrass the anatomist. There are parts of the eye which assist in perfecting the organ of vision, whose nature and functions are among the desiderata of science. We are ignorant of the office of the optic nerve, or in what manner it performs that office. That it has some part in the faculty of seeing, is evident; because in an amaurosis, which is said to be a disorder of the optic nerve, the pictures on the retina are clear and distinct, and yet there is no vision.

We know still less of the use and functions of the choroid membrane, it is necessary however to vision; for it is well known, that a picture upon that part of the retina where it is not covered with the choroid, namely, at the entrance of the optic nerve, produces no more vision than a picture on the hand.† There are, therefore, other material organs, whose operations are necessary to seeing, even after the pictures upon the retina are formed; whenever we become acquainted with the use of these parts, more links of the chain will be brought into our view, and we shall better comprehend this wonderful instrument.

* *Reid* on the Human Mind.

† This is not conclusive, for where there is no choroid there is no retina, the optic nerve being not yet expanded into that membrane. If the choroid was taken away from behind the retina, there is reason to believe that vision would still take place

Having mentioned that there is no vision produced where the nerve enters on that part of the retina which is not covered by the choroid membrane, it will be proper to illustrate this more fully, and shew in what manner this fact has been ascertained, the discovery of which occasioned a long controversy concerning the proper seat of vision.

Experiment. Fix three black patches, A, B, C, *plate* 3, *fig.* 3, upon a white wall at the height of the eye, A being to the left, and C to the right: place yourself facing these patches, shut the right eye, and direct the left towards the patch C, you will then see both A and C, but the middle patch, B, will disappear. Or, if the left eye be shut, and the right directed towards A, you will still see both A and C, but B will disappear. If the eye be directed towards B, both B and A will be seen, and not C; for which ever of the patches is directly opposite to the optic nerve vanishes. This experiment is rather difficult at first, but becomes easy by a little practice. In our usual intercourse with common objects, we are not sensible of this defect, because we turn the visual part of the eye with so much rapidity upon the invisible part of the object, that the loss, without peculiar attention, is imperceptible; this loss, however in one eye, is remedied by the use of both, as the part of the object that is not seen by one, will be distinctly perceived by the other. This defect of sight, though common to every human eye, was never known, until it was discovered by the sagacity of M. *Mariotte* in the last century.

OF THE EXTENT OR LIMITS OF VISION.

Having considered the general principles of vision, I shall now proceed to consider further the nature, properties, and extent of power of the eyes. As in a dark chamber, a very slender beam of light is visi-

ble, so in all cases when the surrounding medium is very dark, objects are seen by small quantities of light. Hence, when the medium round the eye is dark, a small quantity of light will suffice for vision, the eye being, by the exclusion of adventitious light, rendered sensible to the most delicate impressions.

The extent, therefore, of our sight is increased or diminished, in proportion to the quantity of light that surrounds us, supposing the illumination of the object to remain the same. Hence it has been calculated, that if the same object, which during the day we see at the distance of 3436 times its diameter, were equally illuminated during the night, it would be visible at 100 times greater distance.

Thus in a dark night, the feeble light of a candle may be seen at a great distance; and the fixed stars, though they have no sensible diameter, are visible, and the darker the night, the more of them are seen. A certain quantity of light is however necessary, even in this case, for vision; for the impressions of light from the satellites of Jupiter and Saturn are too feeble to be perceived without the assistance of a telescope.

At the approach of day, and as the twilight increases, the eye begins to be enlightened by the reflexion of the atmosphere, the stars grow fainter, and, in proportion as the light increases, gradually disappear, first those of the least, and at last those of the largest magnitude. As the day advances, the moon herself loses of her lustre, till at length her light is overpowered, and she is no longer seen. In the same manner, small particles are seen floating in a beam of light let into a darkened room; but as soon as the room is enlightened, those particles disappear.

One of the reasons why we are often unable to distinguish distant objects, is the profusion of rays

reflected from intermediate objects, which by their brilliancy prevent us from perceiving the fainter rays that proceed from those which are more distant; so that when the objects are very remote, their picture on the retina is easily obliterated by the vigorous and lively impressions made by those that are nearer. But when the intermediate ones emit a feeble light, when compared to that which proceeds from the more remote ones, these will form a distinct picture on the retina, and become perfectly visible.

The extent of vision is not only limited by the light of the ambient medium, which enters the eye with the pencils of light that proceed from surrounding objects, but it is further impeded by the heterogeneous particles that are constantly floating in the air; these, by their opacity and reflective power, form a kind of veil that obscures the vision of remote objects; and the more the medium is loaded with these particles, and the more remote the object is from the spectator, the more obscure and indistinct it will appear, and the limits of vision be more confined.

The exhalations which continually rise from the earth augment this obscurity, and render the air less transparent, especially near the earth: the celestial bodies generally, therefore, appear more obscure when near the horizon, than when they are at a greater elevation; because, in the first case, they are seen through that part of the atmosphere which is contiguous to the surface of the earth; but in the latter, through a part which is at a greater distance.

Every one knows, that objects at a given distance are more distinctly seen, and are visible at a greater distance in clear than in foggy weather. Thus, early in a clear morning, and when the air is free from vapours, and not much enlightened, a hill or a head-land is visible at a great distance; but, as the day advances, the land becomes more obscure,

till at length, by the great opacity of the intervening vapour, and the light reflected to it by the eye, the object becomes less and less perceptible, and at last totally disappears. Hills, and other high lands, are seen more distinctly in the morning, partly from this circumstance, that by their elevation they are more illuminated than the parts intervening between them and the spectator.

But the obscurity arising from the exhalations is not the least part of the inconvenience they occasion; the rising exhalations have a kind of undulating motion, like that of smoke or steam, so that objects seen through them appear to have a tremulous or dancing motion, which is sensible even to the naked eye. If distant objects be viewed in a hot summer's day, this effect is so sensible in telescopes, as to render them entirely useless for terrestrial objets, when they augment apparent magnitude more than eighty times.

From this want of transparency in the atmosphere, arises that gradual diminution in the light of objects, which painters call the aerial perspective, by which they endeavour to give that degradation of colour, and indistinctness of outlines, peculiar to objects at a distance: for if the air were perfectly transparent, an object would be equally luminous at all distances, because the visible area and the density of light decrease in the same proportion.

Another cause which limits the extent of vision, and for the removal of which optical instruments are more particularly adapted, is their smallness in proportion to their distances: for, excepting in the case of luminous objects seen in the dark, it is necessary that an image on the retina should have some determinate magnitude, in order to become perceptible; thus a house may be seen at a considerable distance, but we must approach nearer before the

windows are discernible, and still nearer to distinguish the bricks.

It is not easy to determine with accuracy the quantity of the *minimum visibile*, or the angle that is subtended by the smallest visible object. Mr. *Harris* has inferred, from several experiments, that objects are seldom visible under an angle less than forty seconds of a degree, and at a medium not less than two minutes.

A simple object, as a white or black square, upon the opposite colour, is perceivable under a less angle than the parts of a compound one. The more objects differ in colour, the more easily we can distinguish their several impressions on the retina: different degrees of light on the same object will render it visible at different distances, and under different angles: indeed the most general cause of the invisibility of objects, is the want of sufficient light in the pencils that proceed from them; several contiguous objects are scarcely discernible one from the other, unless they each subtend angles that are not less than four minutes.

A long slender object is visible under a smaller angle than a square object of the same breadth: a slender object, as a line, may be considered as consisting of several squares joined together; and though one of these squares may be too small to be seen, yet the pencils of light coming from each of them being contiguous, and striking at the same time upon the retina, are capable, by their united strength, to awaken the visive faculty, and so to render the objects visible from whence they came. For the same reason, a small object in motion is easier discerned than if at rest, and may be visible in the one case, though not in the other. A small star, by day or twilight, that cannot be easily seen through a telescope directed to it, will become visible by shaking or moving the telescope.

There is a great difference in the degree of sensibility of different eyes. We have been told of persons seeing the satellite of Jupiter without the assistance of glasses: a circumstance that to many appears incredible. But when we consider how much the various circumstances of light affect vision, and how much further our sight is extended at some favourable opportunities than at others, these extraordinary accounts may be the more readily credited.

The following calculation of M. *de la Hire* will give some idea of the extreme sensibility of the optic nerves. The sail of a windmill, six feet in diameter, may be easily seen at the distance of 4000 toises, and the eye being supposed to be an inch in diameter, the picture of this sail at the bottom of the eye will be the eight-thousandth part of an inch. This shews with what wonderful accuracy the rays of light are refracted by the eye, so that a pencil of rays coming from one point of the object, shall meet in a point on the retina, so as not to deviate the eight-thousandth part of an inch.

If an object be held too close to the eye, it becomes indistinct, and the more so the closer it is held, notwithstanding its apparent magnitude is thereby increased, and a very slender object will become totally invisible.

To the generality of eyes, the nearest distance of distinct vision is about seven or eight inches; at this distance they commonly read a small print, and examine all minute objects. It is true, some eyes can see small objects best at the distance of six, four, and even three inches; and some again at twelve, fifteen, or twenty inches; but these are only particular cases, and do not, therefore, affect the present inquiry.

A globular object that is less than $\frac{1}{650}$ inch in diameter, is, to the generality of eyes, totally invisible; and, excepting in a few cases, an object cannot be seen that is less than $\frac{1}{430}$ inch in diameter; an object of that breadth subtending an angle of one minute, at the distance of eight inches from the eye. But when the field, on which the object is placed, is nearly of the same colour with it, we cannot see it under an angle less than about four minutes. In such circumstances the smallest visible object is not less than $\frac{1}{100}$ of an inch in diameter. At a medium, the size $\frac{1}{300}$ inch diameter is the size of the least globular object discernible by the naked eye.

OF DISTINCT AND INDISTINCT VISION.

It will be proper in this place to explain, with more accuracy, what is meant by distinct vision, and what is the difference between seeing an object distinctly, and seeing it clearly; as the clearness or brightness with which an object is seen, is often confounded with distinct vision.

We see an object clearly, when it is sufficiently illuminated, to enable us to form a general idea of its figure, and distinguish it from other objects: we see it distinctly, when the outlines of it are well defined, when we can distinguish the parts of it, and determine their colour and situation. Thus we may be said to see a distant object clearly, when we can perceive that it is a tower; but to see it distinctly, we approach so near as to be able to determine not only its general outline, but to distinguish the parts of which it is composed.

This may be made more evident, by adverting to the experiment of the dark chamber, in which we shall find a considerable difference between the distinctness and brightness of the picture; and learn,

that a confusion of the parts is not the same thing with obscurity.

For the picture may be distinct in all its parts; the rays which come from one and the same point in the object, may be exactly collected into one and the same point upon the paper; and yet, if but a few rays pass through the lens, and consequently the space where the picture is painted should be but faintly enlightened, this picture, though it is distinct, will be faint and obscure. On the other hand, though the picture be confused, either because the paper is placed at an improper distance from the lens, or for any other cause; yet, if many rays pass through the lens, and strongly illuminate the paper, the picture, notwithstanding the want of distinctness, will be a bright one.

The brightness or clearness with which an object is seen, depends principally on the following circumstances.

1. On the quantity of light proceeding from the object to the eye; and this is in a great measure regulated by the distance, for the intensity of light diminishes in an inverse ratio to the square of the distances.

2. It depends on the colour of the object itself, and of those objects which surround it.

3. On the manner in which the light falls upon the object, and is reflected from it.

4. On the aperture of the pupil, for the wider this is, the greater will be the number of rays that are transmitted to the retina.

5. On the transparency and purity of the humours of the eye, and the soundness of the rest of the visive parts.

6. On the transparency of the atmosphere.

When all these circumstances concur, an object will appear bright and clear; but less so, in proportion as any of them are wanting. In order, how-

ever, to obtain distinct vision, it is requisite, not only that the object be sufficiently illuminated, but also that the several pencils, on their arrival at the retina, should be separate, and not mixed together; and when this is not the case, the outlines of the object and its parts will appear faint, hazy, and ill-defined. We may, therefore, consider the following conditions as necessary towards obtaining distinct vision.

1. The objects should be sufficiently illuminated: now, all other circumstances being the same, the nearer an object is, and the brighter its colour, the more light the eye receives from it; this is one reason why near objects are more distinctly seen than those that are more remote.

2. The geometrical image of objects should fall either upon the retina, or very near it, and these images should be sufficiently large, otherwise the parts of the object cannot be distinctly perceived: the want of size in this image is also a cause of the indistinctness of remote objects.

3. It is also requisite that the eye be in perfect order, and its humours transparent, in order that the impressions of light may be lively and distinct.

In a given eye, and a given disposition of that eye, an image upon the retina will be most perfect when the object is at some determinate distance from the eye; and it is near this point or place, that objects, if they are not too small, will be distinctly seen. An object at a greater or less distance, will have its image either before or behind the retina; and, in either case, if the distance of the image from the retina be considerable, the vision will be indistinct.

Dr. *Jurin* has, however, shewn, that it is not necessary to distinct vision, that the images of objects, or the points of union of the rays, be precisely upon the retina, there being some latitude both before

and behind the retina, within which, whatever images be formed, the vision will be equally distinct; and this latitude will be the greater or less, according as the visual angles subtended by the respective objects, are greater or less.

Let a printed page, in which there are letters of three or four different sizes, be placed at such a distance, that every sort of print may, without any straining or effort of the eye, be perfectly distinct; in this case it may be reasonably presumed, that the images of the several letters fall upon the retina. If the printed leaf be brought gradually nearer and nearer, the smallest print will first begin to be confused, whilst the larger remains as distinct as before: by advancing it still nearer, the smaller print will become more confused, the next size above it a little confused, whilst the large print is still as legible as before; and so through several degrees, till the whole is in confusion.

The same experiment may be made the contrary way, by using a pair of spectacles of a proper convexity. From hence it is evident, that we may have distinct vision, when the foci of the pencils are at some distance, either before or behind the retina, and that the larger the object, the greater is this latitude.

But as in this case the pencils from every point either meet before they reach the retina, or tend to meet beyond it, the light that comes from them must cover a circular spot upon it, and will, therefore, paint the image larger than the perfect vision would represent it: and, consequently, every object, placed either too near or too remote for perfect vision, will appear larger than it is, by a penumbra of light, caused by the circular spaces, which are illuminated by pencils of rays proceeding from the extremities of the objects. These circular spaces are called circles of dissipation. This accounts for short-sighted

persons finding near objects appear rather magnified, when they use a concave glass which is not so much concave as that to which they are accustomed.

On account of these penumbræ, it is clear, that two stars will appear to be nearer than they really are; and if they be really very near, will appear to be but one, but brighter than either of them taken alone: so that the two stars will have the same appearance as if one brighter star appeared in the middle of the space occupied by two stars.

When objects are large, they will appear tolerably distinct at a much less distance than small objects, because the penumbræ will not interfere so much. For this reason, a large print may be read much nearer the eye than a small one; the former will appear only ill-defined, but sufficiently distinct, when the latter is quite indistinct, the penumbra of one letter interfering with that of another.

It is very difficult to ascertain precisely the natural distance of distinct vision, or that distance at which the eye, without any strain or effort, is suited to see objects distinctly. If we suppose this distance to be that at which we usually read a large fair print, this will be about fifteen or sixteen inches, and it cannot be less, as we are rather more concerned with large objects than the letters of a book; and when we view objects nearer, it is on account of their minuteness: nor is it probable that the distance can be many feet, as, in order to examine objects, we are always desirous to have them near the eye, except they are very large. The nearest distance of distinct vision is in general computed to be about seven or eight inches from the eye. That point in any object, to which the optic axis is directed, is seen more distinctly than the rest. The truth of this position is confirmed by every one's experience: if if we turn our eyes directly toward one particular part of an object so as to look steadily at it, we may

indeed, if the object be not very large, see all the rest of it at the same time; but this part will appear more distinct than the rest: but looking steadily at an object is turning our optic axis towards it.

OF THE CHANGE IN THE CONFORMATION OF THE EYE FOR DISTINCT VISION, AT DIFFERENT DISTANCES.

As a ship requires a different trim for every variation of the direction and strength of the wind, so, if we may be allowed to borrow that word, the eyes require a different trim for every degree of light, and for every variation in the distance of the object, while it is within certain limits. The eyes are trimmed for a particular object, by contracting certain muscles, and relaxing others; as the ship is trimmed for a particular wind, by drawing some ropes, and slackening others. The sailor learns this trim of his ship, as we learn the trim of our eyes, by experience.*

A ship, although it be the noblest machine that human art can boast, is far inferior to the eye; for it requires art and ingenuity to navigate her, and the sailor must know what ropes to pull, and which to slacken, to accommodate her to a particular wind. But the eye is fabricated with such superior wisdom, and the principles of its motion so contrived, that it requires no art nor ingenuity to see by it: we have not to learn what muscles we are to contract, nor which we are to relax, in order to fit the eye to a particular distance of the object.

But although we are not conscious of the motions we perform, in order to fit the eyes to the distance of the object, we are conscious of the effort employed in producing these motions, and probably have some

* *Reid's* Inquiry into the Human Mind.

sensation which accompanies them, and to which we give as little attention as to many other sensations; and thus a sensation, either previous or consequent upon that effort, comes to be conjoined with the distance of the object which gave occasion to it, and by this conjunction becomes one of the signs of that distance.

That we are capable of viewing objects with nearly equal distinctness, though they are placed at considerable distances from each other, is evident; but the alteration which takes place in the eye for this purpose, or the mechanism by which this effect is produced, is not easily ascertained.

It seems clear from the first view of the subject, that when several objects are at different distances before us, they will not appear equally distinct at the same time. Lest it should be suspected, that the indistinctness in this case may be owing to the impressions not being made upon the corresponding fibrils of the two retinas, let us make a trial with one eye alone, while the other is shut: thus place two small objects, as two pins, one behind the other, and let one be at a foot, and the other at about six inches distance from the eye. Either of these objects, when looked at attentively, will appear distinct; but the other, at the same time, although it be in the axis of the eye, will be confused. And from hence it is very clear, that the same conformation of the eye is not adapted for distinct vision at all distances, and that the eye by some means changes its conformation, so as it may be better suited for vision at different distances.

In a similar manner to the foregoing experiment, if the eye looks attentively upon the little scratches or particles of dust upon a window-glass, the objects without doors will be indistinct; and when we look at the external objects, the opake particles upon the glass, which before were distinct, will now be con-

fused. It also frequently happens, that when we first look at an object, it will appear very confused, which confusion will vanish by degrees, and in a little time the object will become quite distinct.

In like manner, if after poring some time on a book, we suddenly look at objects farther off, they will at first appear confused, and become distincter by degrees. A similar indistinctness takes place, when, from looking at remote objects, we suddenly look at one that is near. To what can we attribute these phenomena, but to a change in the conformation of the eye for vision at these different distances? A change which requires some small time for its performance. It cannot be owing to the last impression on the eye not being obliterated; for in that case, the same confusion would be observable upon shifting the eye from one page of the book to the other.

These phenomena are stronger when they happen without our thinking upon them; for when we make the experiment on purpose, and the mind is already prepared for what is to happen, it has time in part to frustrate our design; the more so, as these changes are somewhat painful.

Authors are much divided in their opinions concerning the change that is made in the conformation of the eye, to procure distinct vision at different distances; some thinking it to be a change in the length of the eye, others that it is a change in the figure or position of the crystalline humour, others that it is a change in the cornea. The authors of each opinion have their objections to all the rest, and perhaps the truth may lie among them all. As the rays of light suffer a greater refraction at the cornea than they do afterwards, it is plain, that a less change, as to quantity, in the radius of the cornea, will effect the business, than would be sufficient in any other part of the eye: but at the same time it must

also be confessed, that most persons who have been couched for cataracts, are obliged to have glasses of different convexities, in order to have distinct vision at different distances; from whence it seems necessarily to follow, that the crystalline humour is concerned in changing the conformation of the eye. Perhaps the cornea, and the crystalline, if not some other parts of the eye besides, may contribute to produce this effect: and in order to obtain distinct vision at a nearer distance, at the same time the cornea is rendered more convex, the axis of the eye may be a little lengthened, the crystalline made more convex and brought forwarder, all which changes conspire to the same end; and the contrary for obtaining vision at a greater distance.*

It has been shewn by writers on optics, that if an object be viewed distinctly at three different distances from the eye, the first of which may be the least distance at which it can be viewed distinctly, the second double the first, and the third infinite, the alterations in the conformation of the eye, necessary for viewing an object distinctly at the first and second distances, whose difference is but small, are as great as those that are necessary for the second and third, whose difference is infinite.

Hence, if a short-sighted person can read a small print distinctly at two different distances, whereof

* By some experiments made by Mr. *Home*, Mr. *Ramsden*, and Sir *H. Englefield*, in an endeavour to shew that the adjustment of the eye to different distances could take place independently of the crystalline lens, by a change of curvature in the camera, the result produced was, that one-third of the adjustment of the eye to different distances might be attributed to the change of curvature in the cornea, and the remainder of the effect divided between the elongation of the axis of vision and a motion of the crystalline lens; and all these changes in a great measure depending on the construction of the four straight muscles of the eye. The extreme nicety of the experiments by an optical apparatus, rendered the particulars not very satisfactory. See Philos. Trans. 1795 and 1796. EDIT.

the larger is but double the lesser, as great alterations are made in his eyes, as in one whose eyes are perfect, and that can see distinctly at all intermediate distances, between infinity and the largest of the two former distances. For the same reason, a short-sighted person can see distinctly at all distances, with a single concave of a proper figure; for the cause of short-sightedness is not a want of power to vary the conformation of the eye, but that the whole quantity of refractions is always too great for the distance of the retina from the cornea.

We may hence also clearly perceive why our eyes are so often fatigued in looking at near objects; for in this case, the muscles of the eyes, and the ligamentum ciliare are obliged to make a considerable effort to give the eyes the necessary conformation; which effort being greater in proportion as the object is nearer, must be painful and laborious when the object is very nigh.

When the eye has been attentively fixed on an object at some determined distance, it cannot immediately see another object distinctly; whether it be at a greater or less distance, it appears confused and imperfect, till the eye has adapted itself to the distance at which the object is placed.*

* In the Philosophical Transactions, part 1, 1796, is related by Mr. *Home* " a very remarkable fact, relative to the quickness of sight, or of some other sense, but most probably of sight, in the vulture tribe. Some gentlemen, on a hunting party in the island of Cassimbusar in Bengal, killed a wild hog of uncommon size, and left it on the ground near their tent. About an hour afterward, they were walking near the place, when they discerned in a perfectly clear sky, a dark spot at a great distance. It gradually increased as it advanced towards him, and proved to be a vulture, which flew in a direct line to the dead animal, and, alighting on it, began to feed voraciously. Within less than an hour, it was joined by 70 others, which came from all quarters, mostly from the upper regions of the air; in which a few minutes before nothing could be seen." EDIT.

OF THE PUPIL OF THE EYE, AND OF ITS MOTIONS.

In speaking of the structure of the eye, we have shewn, that the uvea has a small round hole nearly in the middle, called the pupil, through which the rays must all pass before they can get to the bottom of the eye, and paint the images of objects on the retina. The considerations of the various affections of this part of the eye, will be found of great importance, both to the vender and purchaser of spectacles; for upon the state and aperture of the pupil, the requisite degree of magnifying power very much depends.

The Author of Nature has proportioned the magnitude of the pupil, so that it may best answer the purposes of vision, and the sensibility of the retina: if it were too large, the retina would be fatigued, and hurt by the great quantity of light. Hence it is, that those creatures cannot bear the light of the day, which, in order to search for and procure their food at night, have the pupil of their eyes very large. Further, if this aperture had been much larger than it really is, the eye would not have been a dark cell, and so much adventitious light would have entered, as to render the picture upon the retina obscure and indistinct: for, as in the camera obscura, the pictures are most lively and perfect when all the light is excluded, but what comes from the object, and serves to form the picture; so it is with our eyes; the picture on the retina is most perfect when all the extraneous light is excluded, and none mixes with the picture, but what tends to its formation.

On the other hand, if the pupil had been very small, it would not have admitted a sufficient quantity of light; the impression on the retina would have been weak, and the picture faint and obscure;

when the pupil is very small, convex glasses are necessary, in order to increase the quantity of light.

All animals have a power of contracting and dilating the pupil of their eyes. The natural state appears to be that of dilatation, and the contraction a state of violence, produced by an effort originating in the mind. When the light is too strong, or the object too bright, we contract the pupil, to intercept that part of the light which would injure the eye; but when the light is weak, we dilate the pupil, that more light may enter the eye. If a person looks towards the sun, you will observe the pupil become exceeding small; but if he turns his eyes from the light, and be gradually brought into a dark place, you will observe the pupil to dilate, in proportion as the light becomes more faint and obscure.

There are also other circumstances which will cause the pupil to contract, as when the object is nearer the eye than the limits of distinct vision: for in this case, the pencils of rays proceeding from the object are too diverging to be united in corresponding points on the retina; but, by contracting the pupil, many of the rays are excluded, and the picture is rendered more distinct. It is for this purpose, that many short-sighted persons contract a habit of corrugating their eyebrows in reading; a habit which would be prevented by the use of concave spectacles.

Dr. *Jurin* has shewn, that the contraction of the pupil does, in general, depend more upon the strength of light, than on the sensation of a confusion in the object. Let any person take a book by day-light, and stand near the middle of a room, with his back to the light, and then hold the book so near that the letters may appear indistinct, but not so much so, but that they may be read, though with difficulty; on turning towards the light, it

will be read with more ease. Again, holding the book at the same distance, go into the darkest part of the room, and standing with your back to the light, you will find the book not at all legible; but on coming to the window, with your face to the light, you will be able to read with ease and distinctness. A person who has used spectacles for some years will, in the sun-shine, be able to read without them.

When we have been for some time in a place much illuminated, or if the eye has been too long exposed to a resplendent object, and then views objects that are less so, or goes into a darker place, the sight will for a little time be impaired, and the eye unable to perform its proper functions. The same will also happen from the contrary circumstances, if we go from a faint light into one that is much brighter; in either case the pupil has not time to conform itself to the sudden,* but necessary change, for seeing distinctly under the new circumstances. From hence we may infer, that very opake shades round a candle, instead of preserving and protecting the eye, must be necessarily prejudicial to it. A moderate degree of opacity in the shade, as that of thick paper, may, by lessening the degree of light, be useful to eyes which are inflamed, or have a tendency to inflammation.

There is a kind of sympathy or concord in the motion of the pupils of both eyes, so that when one is contracted, the other contracts also, when one is dilated, the other also dilates, though neither the dilatation nor contraction are equal. Many gross oversights have arisen, and some dangerous mistakes

* This is what *Porterfield* and some others say; but from other experiments, the pupil is never so contracted as in the case of going suddenly from a faint to a bright light: the contraction is instantaneous. The effects, therefore, spoken of above, must be referred to the different states of the sensibility of the retina.

have been made by oculists, according to *Potterfield*, from their not attending to this fundamental law concerning the pupil.

From this expanding and contracting power of the eye, we may learn why the eye sees best when surrounded with darkness; for the pupil, by dilating, accommodates itself as much as possible to the quantity of light, dilating considerably when the eye is in darkness, and, *cæteris paribus*, objects are seen most clearly when the pupil is most dilated. Besides, when the eye is in the dark, the picture on the retina is neither confused nor disturbed by adventitious rays: hence, those who are in a very bright light, when they want to distinguish accurately a distant object, either depress the eyebrows, or apply the hand to the forehead: hence also, a person, by placing himself in the dark and employing a long tube, will form a species of telescope producing a greater effect than might at first be conceived: it was on this principle that the ancients used a deep pit, in order to see the stars in the daytime. From hence we also learn, why a person from within a chamber can perceive the objects that are without, while those that are out of doors cannot see the objects that are within: for, when we are out of doors, the pupil is contracted, and only a small portion of the light that is reflected from the objects within the chamber can pass to the retina; while, on the contrary, those within have the pupil more dilated, and the objects that are without are also more strongly illuminated; besides which, their view of objects is not so much obstruced by the reflexion of the window-glass.

It is surprizing how far the eye can accommodate itself to darkness, and make the best of a gloomy situation. When first taken from the light, and brought into a dark room, all things disappear; or if any thing is seen, it is only the remaining radia-

tions that still continue in the eye; but after a very little time, the eye takes advantage of the smallest ray, which is confirmed by the following curious account related by Mr. *Boyle*. In the time of *Charles* I. there was a gentleman, who, sharing in his worthy master's misfortunes, was forced abroad; at Madrid, in attempting to do his king a signal service, he failed; in consequence of this, he was confined in a dark an dismal dungeon, into which the light never entered, and into which there was no opening but by a hole at the top, down which the keeper put his provisions, presently closing it again. The unfortunate loyalist continued for some weeks in this dark dungeon, quite disconsolate; but, at last, began to think he saw some glimmering of light: this dawn of light increased from time to time, so that he could not only discover the parts of his bed, and such other large objects, but, at length, he could perceive the mice that frequented his dungeon, to eat the crumbs that fell upon the ground. When set at liberty, he could not, for some days, venture to leave his cell, lest the brightness of the light should blind him; he was obliged to accustom his eyes, by slow and gradual degrees, to the light of the day.

OF IMPERFECT SIGHT.

There is no branch of science, of which it is more important that a general knowledge should be diffused, than that part which treats of the various imperfections of sight, and the remedies for them. To relieve an organ which is the source of the most refined pleasure, is certainly a desirable object: to enable those, who are in want of assistance, to determine whether spectacles will be advantageous or detrimental, and what kind will best suit their sight; and so instruct those who already use glasses, that

they may discover whether those they have chosen are adapted to the imperfection of their sight, or are such as will increase their complaint and weaken their eyes; are subjects worthy the consideration of every individual, and constitute the principal business of the remainder of this Lecture. To this end, I shall, in the first place, explain what I mean by an imperfection of sight.

The sight is relatively imperfect, when we cannot see an object distinctly in a common light, and at all the usual distances at which it is observed by an eye in a perfect state.

In this sense, both the long and short sighted are said to have an imperfect sight. The short-sighted see distant objects confusedly, those that are near at hand distinctly; their sight is therefore defective with respect to distant objects: on the other hand, the long-sighted see distant objects distinctly, near objects confusedly.

An imperfect sight is occasioned by a confusion in the image formed upon the retina; this happens whenever all the rays that proceed from any one point of an object, are not united again in one, but fall on different points of the retina; or whenever several pencils of light from different points of an object terminate upon one point of the image. This species of confusion takes place both in long and short-sighted eyes.

OF OLD OR LONG-SIGHTED EYES.

To detail those circumstances which are, in general, marks of advancing age, and always of partial infirmity, must be ever unpleasant, and would be equally unnecessary, if it were not the mean of lessening the inconveniences attendant on those stages of life.

By the long-sighted, remote objects are seen distinctly, near ones confusedly; and in proportion as this defect increases, the nearer objects become more indistinct, till at length it is found almost impossible to read a common-sized print without assistance. An imperfect and confused image is formed upon the retina, because the rays of light that come from the several points of an object at an ordinary distance, are not sufficiently refracted, and therefore do not meet upon the retina, but beyond it.

Various are the causes which may occasion this defect; if the convexity of the cornea be lessened, or if either side of the crystalline becomes flatter, this effect will be produced; if the retina be not sufficiently removed from the cornea or crystalline, or if the retina be too near the cornea or crystalline, it will give rise to the same defect, as will also a less refractive power in the pellucid parts of the eye; in like manner, too great a proximity of the objects will prevent the rays from uniting till they are beyond the retina; but if all these causes concur together, the effect is greater.

This defect is, however, in general attributed to a shrinking of the humours of the eye, which causes the cornea and crystalline to lose their original convexity, and to become flatter: the same cause will bring the retina too near the cornea.

By one or other of these causes, those who were accustomed in their youth to read a common size print, at about twelve or fourteen inches distance from their eyes, are obliged to remove the book two or three feet before they can see the letters distinctly, and read with comfort. But in proportion as the object is removed from the eye, the image thereof on the retina becomes smaller, and consequently small objects will not always be perceivable at that

distance, to which those in this state find it necessary to remove them, in order to attain any degree of distinct vision: the further also the object is removed, the less light will enter the eye, and the image will of course be fainter.

Hence, those who are long-sighted require more light to enable them to read, than they did while their eyes were in their perfect state; and this not only because they are obliged to remove the book to a greater distance, but because the pupil of their eye is smaller, and therefore a greater intensity of light is necessary to produce a sufficient impression on the retina, and compensate for the defect by a greater splendor and illumination of the object.

Increasing years have a natural tendency to bring on this defect, and earlier among those who have made the least use of their eyes in their youth; but whatever care be taken of the sight, the decays of nature cannot be prevented: the humours of the eye will gradually waste and decay, the refractive coats will become flatter, and the other parts of the eye more rigid and less pliable; thus the latitude of distinct vision will become contracted: it is also highly probable, that the retina and optic nerve lose a portion of their sensibility.

Though it is in the general course of nature, that this defect should augment with age, yet there are not wanting instances of those who have recovered their sight at an advanced period, and have been able to lay aside their glasses, and read and write with pleasure, without any artificial assistance. Among many causes which may produce this effect, the most probable is, that it generally arises from a decay of the fat in the bottom of the orbit; the pressure in this part ceasing, the eye expands into somewhat of an oval form, and the retina is removed to a due focal distance from the crystalline.

It is a certain and very important fact, that long-sightedness may be acquired; for countrymen, sailors, and those that are habituated to look at remote objects, are generally long-sighted, want spectacles soonest, and use the deepest magnifiers: on the other hand, the far greater part of the short-sighted are to be found among students, and those artists who are daily conversant with small and near objects; every man becoming expert in that kind of vision, which is most useful to him in his particular profession and manner of life. Thus the miniature painter and engraver see very near objects better than a sailor; but the sailor perceives distant objects better than they do; the eye in both cases endeavouring to preserve that configuration to which it is most accustomed. In the eyes, as well as other parts of the body, the muscles, by constant exercise, are enabled to act with more ease and power, but are enfeebled by disuse: the elastic parts also, if they are kept too long stretched, lose part of their elasticity; while on the other hand, if they be seldom exercised, they grow stiff, and are not easily distended. From the consideration of these facts, we may learn in a great measure how to preserve our eyes; by habituating them occasionally to near as well as distant objects, we may maintain them longer in their perfect state, and be able to postpone the use of spectacles for many years; but we may also infer from the same premises, that there is great danger, when the eyes are become long-sighted, of deferring too long the use of spectacles, or using those that magnify too much, as we may by either method so flatten the eye, as to lose entirely the benefits of naked vision. It may not be improper in this place to remark, that the long-sighted eye is much more liable to be injured by too great a degree of light, than those that are short-sighted.

Objects that appear confused to the long-sighted, will be rendered more distinct, if they view them through a small hole, such as that made by a pin in a card, because it excludes those diverging rays which are the principal source of confusion; but as it at the same time intercepts a considerable portion of the light, it is by no means an adequate remedy. The best relief they can obtain is from convex glasses; for by these the rays of light that proceed from the object are so refracted, as to fall upon the retina, in the same manner as if they issued from a distant point. Spectacles afford two advantages, for they not only render the picture of the objects distinct upon the retina, but they also make it strong and lively.

OF SPECTACLES.

Spectacles restore and preserve to us one of the most noble and valuable of our senses; they enable the mechanic to continue his labour, and earn a subsistence by the work of his hand, till the extreme of old age. By their aid the scholar pursues his studies, and recreates his mind with intellectual pleasures, and thus passes away days and years with delight and satisfaction, that might otherwise have been devoured by melancholy, or wasted by idleness.

As spectacles are designed to remedy the defects of sight, it is natural to wish that the materials of which they are formed should be as perfect as the eye itself; but vain is the wish! for the materials we use, like every thing human, are imperfect, and yet we may deem ourselves happy, to have in glass a substitute so analogous to the humours of the eye, a substance which gives new eyes to decrepid age, and enlarges the views of philosophy. The two principal defects are, small threads or veins in the

glass, and minute specks. The threads are most prejudicial to the purposes of vision, because they refract the rays of light irregularly, and thus distort the object, and fatigue the eye; whereas the specks only lessen the quantity of light, and that in a very small degree.

GENERAL RULES FOR THE CHOICE OF SPECTACLES.

The most general, and, perhaps, the best rule that can be given, to those who are in want of assistance from glasses, in order so to choose their spectacles that they may suit the state of their eyes, is to prefer those which shew objects nearest their natural state, neither enlarged nor diminished, the glasses being near the eye, and that give a blackness and distinctness to the letters of a book, neither straining the eye, nor causing any unnatural exertion of the pupil.

For no spectacles can be said to be properly accommodated to the eyes, which do not procure them ease and rest; if they fatigue the eyes, we may safely conclude, either that we have no occasion for them, or that they are ill-made, or not proportioned to our sight.

Though, in the choice of spectacles, every one must finally determine for himself which are the glasses through which he obtains the most distinct vision; yet some confidence should be placed in the judgment of the artist, of whom they are purchased, and some attention paid to his directions.

OF PRESERVERS, AND RULES FOR THE PRESERVATION OF SIGHT.

Though it may be impossible to prevent the absolute decay of sight, whether arising from age, par-

tial disease, or illness; yet by prudence and good management, its natural failure may certainly be retarded, and the general habit of the eyes strengthened, which good purposes will be promoted by a proper attention to the following maxims.

1. Never to sit for any length of time in absolute gloom, or exposed to a blaze of light. The reasons on which this rule is founded, prove the impropriety of going hastily from one extreme to the other, whether of darkness or of light, and shew us that a southern aspect is improper for those whose sight is weak and tender.

2. To avoid reading a small print.

3. Not to read in the dusk; nor, if the eyes be disordered, by candle-light. Happy those who learn this lesson betimes, and begin to preserve their sight, before they are reminded by pain of the necessity of sparing them; the frivolous attention to a quarter of an hour of the evening, has cost numbers the perfect and comfortable use of their eyes for many years: the mischief is effected imperceptibly, the consequences are inevitable.

4. The eye should not be permitted to dwell on glaring objects, more particularly on first waking in a morning; the sun should not, of course, be suffered to shine in the room at that time, and a moderate quantity of light only be admitted. It is easy to see, that for the same reasons the furniture of a bed should be neither altogether of a white or red colour; indeed, those whose eyes are weak, would find considerable advantage in having green for the furniture of their bed-chamber. Nature confirms the propriety of the advice given in this rule; for the light of the day comes on by slow degrees, and green is the universal colour she presents to our eyes.

5. The long-sighted should accustom themselves to read with rather less light, and somewhat nearer

to the eye, than what they naturally like; while those that are short-sighted should rather use themselves to read with the book as far off as possible. By these means, both would improve and strengthen their sight; while a contrary course will increase its natural imperfections.

There is nothing which preserves the sight longer than always using, both in reading and writing, that moderate degree of light which is best suited to the eye; too little strains them, too great a quantity dazzles and confounds them. The eyes are less hurt by the want of light than by the excess of it; too little light never does any harm, unless they are strained by efforts to see objects, to which the degree of light is inadequate; but too great a quantity has, by its own power, destroyed the sight. Thus many have brought on themselves a cataract, by frequently looking at the sun, or a fire; others have lost their sight, by being brought too suddenly from an extreme of darkness into the blaze of day. How dangerous the looking upon bright luminous objects is to the sight, is evident from its effects in those countries which are covered the greater part of the year with snow, where blindness is exceeding frequent, and where the traveller is obliged to cover his eyes with crape, to prevent the dangerous, and often sudden effects of too much light: even the untutored savage tries to avoid the danger, by framing a little wooden case for his eyes, with only two narrow slits. A momentary gaze at the sun will, for a time, unfit the eyes for vision, and render them insensible to impressions of a milder nature.

The following cases from a small Tract on the Fabric of the Eye, are so applicable to the present article, as to want no apology for their insertion here; though, if any were necessary, the use they will probably be of to those whose complaints arise

from the same or similar causes, would, I presume, be more than sufficient.

"A lady from the country, coming to reside in St. James's-square, was afflicted with a pain in the eye, and a decay of sight. She could not look upon the stones, when the sun shone upon them, without great pain. This, which she thought was one of the symptoms of her disorder, was the real cause of it. Her eyes, which had been accustomed to the verdure of the country, and the green of the pasture grounds before her house, could not bear the violent and unnatural glare of light reflected from the stones; she was advised to place a number of small orange trees in the windows, so that their tops might hide the pavement, and be in a line with the grass. She recovered by this simple change in the light, without the assistance of any medicine; though her eyes were before on the verge of little less than blindness."

"A gentleman of the law had his lodgings in Pall-mall, on the north-side, his front windows were exposed to the full noon sun, while the back room, having no opening, but into a small close yard surrounded with high walls, was very dark; he wrote in the back room, and used to come from that into the front to breakfast, &c. his sight grew weak, and he had a constant pain in the balls of his eyes; he tried visual glasses, and spoke with oculists equally in vain. Being soon convinced, that the coming suddenly out of his dusky study into the full blaze of sun-shine, and that very often in the day, had been the real cause of the disorder, he took new lodgings; by which, and forbearing to write by candle-light, he was very soon cured."

Blindness, or at least miserable weaknesses of sight, are often brought on by these unsuspected causes. Those who have weak eyes should, therefore be particularly attentive to such circumstances,

since the prevention is easy, but the cure may be difficult, and sometimes impracticable.

Whatsoever care, however, be taken, and though every precaution be attended to with scrupulous exactness; yet, as we advance in years, the powers of our frame gradually decay; an effect which is generally first perceived in the organs of vision.

Age is, however, by no means an absolute criterion, by which we can decide upon the sight, nor will it prove the necessity of wearing spectacles. For, on the one hand, there are many whose sight is preserved in all its vigour, to an advanced old age; while, on the other, it may be impaired in youth by a variety of causes, or be vitiated by internal maladies. Nor is the defect either the same in different persons of the same age, or in the same person at different ages; in some the failure is natural, in others is acquired.

From whatever causes this decay arises, an attentive consideration of the following rules will enable every one to judge for himself, when his sight may be assisted or preserved by the use of spectacles.

1. When we are obliged to remove small objects to a considerable distance from the eye, in order to see them distinctly.

2. If we find it necessary to get more light than formerly; as, for instance, to place the candle between the eye and the object.

3. If on looking at, and attentively considering a near object, it becomes confused, and appears to have a kind of mist before it.

4. When the letters of a book run one into the other, and hence appear double and treble.

5. If the eyes are so fatigued by a little exercise, that we are obliged to shut them from time to time, and relieve them by looking at different objects.

When all these circumstances concur, or any of them separately take place, it will be necessary to seek assistance from glasses, which will now ease the eyes, and in some degree check their tendency to grow flatter; whereas, if they be not assisted in time, the flatness will be considerably increased, and the eyes be weakened by the efforts they are compelled to exert.

We are now able to decide upon a very important question, and say how far spectacles may be said to be preservers of the sight. It is plain they can only be recommended as such to those, whose eyes are beginning to fail; and it would be as absurd to advise the use of spectacles to those who feel none of the foregoing inconveniences, as it would be for a man in health to use crutches to save his legs. But those who feel those inconveniences, should immediately take to spectacles, which, by enabling them to see objects nearer, and by facilitating the union of the rays of light on the retina, will support and preserve the sight.

OF COUCHED EYES.

With the diseases of the eye, these Lectures have no concern; they have been already well and ably considered by professional men; and it is scarcely necessary to observe, that in anatomical knowledge, and in the practical operations of surgery, England now claims a just pre-eminence over other nations.

But among the various diseases of this organ, there is one in which, after the surgeon has quitted the patient, glasses are necessary, to give effect to the operation, and a comfortable sight of objects to the person relieved. This disease is the cataract, a disorder affecting the crystalline humour of the eye; when the opacity is confirmed, this humour

becomes so opake, as scarcely to admit any rays of light, and prevents their producing their ordinary effects, and consequently no image of any object is formed, though the retina, and other organs of sight, are in perfect order. There is no disorder more deplorable in its nature and consequences; destructive of the sight often beyond the reach of remedy: the hand of the operator is the only hope, and his efforts are sometimes unsuccessful.

The cause of this disorder is seldom known. Sometimes it has been thought to be brought on by frequent inspection of the sun, and sometimes by looking too long and too often at a bright fire. In early stages of the disease it has been thought to be removed by medicine.* Of the various remedies that have been used for this purpose, the electrical stream is supposed to be the best, on account of its powerful discutient properties.

The assistance the eye receives from the surgeon is either by depression of the crystalline below the pupil, or extracting the cataract. But as the density of the vitreous humour, which supplies the place of the crystalline, is less, the rays of light will be less refracted, and not meet at the retina, but at some distance behind it; the sight will therefore be imperfect, except the eye be assisted with a proper convex glass. There is a circumstance attending

* Baron *de Wenzel*, in his Treatise on the Cataract, denies that any medicine has power to dissipate the opake crystalline. Mr. *Ware*, in his translation of this work, assents to the truth of the Baron's observations, so far as is at present known; but adds, that many cases have occurred, under his own inspection, which prove, that the powers of nature are often sufficient for this purpose. Those opacities in particular, which are produced by external violence, he has repeatedly seen dissipated in a short space of time, when no other parts of the eye have been hurt; and in general, in cases of this description, the crystalline humour has been dissolved; which has been demonstrated, by the benefit the patient has afterwards derived from adopting the use of very convex glasses. Mr. *Ware* adds, that instances are not wanting,

couched eyes, which fully evinces that the change made in our eyes, to accommodate them to the distances of objects, must be principally attributed to the crystalline humour; namely, that one focus is seldom sufficient to enable those who have undergone this operation, to see objects at different distances. They generally require two pair of spectacles, one for near, the other for more distant objects. The foci that are used lie between six and one and an half inches.

It is not adviseable to use glasses too soon after the operation; for while the eyes are in a debilitated state, all exertions are not only improper, but also very prejudicial.

OF THE SHORT-SIGHTED.

In this defect of the eye, the images of objects at an ordinary distance unite before they arrive at the retina, and consequently the images formed thereon are confused and indistinct. This effect is produced either by too great a convexity in the cornea and crystalline, or too great a refractive power in the humours of the eye; or the retina may be placed too far; or it may arise from a concurrence of all these circumstances.

in which cataracts, which are formed without any violence, have been suddenly dissipated, in consequence of an accidental blow on the eye. For these reasons he entertains a hope, that means may hereafter be discovered, by which an opake crystalline may be rendered transparent, without the performance of any operation whatever. The remedies which have appeared to Mr. *Ware* more effectual than others, in these cases, have been the application to the eye itself of one or two drops of æther, once or twice in the course of the day, and the occasional rubbing of the eye over the lid, with the point of the finger, first moistened with a weak volatile or mercurial liniment. See *Ware*'s Translation of *Wenzel*'s Treatise on the Cataract, page 13.

Those who are short-sighted can distinguish smaller objects, and see clearly a given small object with less light than other people: the reason is evident, for the nearer the object is, the more light enters the pupil; being also more dense, its action is more powerful on the retina, and the image depicted larger: hence the short-sighted can read a small print by moon-shine, or in the twilight, when a common eye can scarcely distinguish one letter from another.

In a strong light they can see a little farther than they do in a weak one; the strength of the light causes the pupil of their eyes to contract, and thus removes in some degree the indistinctness of the objects. Upon the same principle we may account for the short-sighted so often partly shutting their eyelids, from whence they were formerly denominated myopes; by this means, they confine the bases of the pencils of rays which issue from the points of an object, and thus contract the circle of dissipation, and lessen the indistinctness of vision: hence they also see objects more distinctly through a small hole, as that made by a pin in a card.

It is a common observation, that the short-sighted do in general prefer a small print to a large one, and that they usually write a small hand; for by the proximity the letters are magnified, and, being small, they take in a greater number at one view; they hold the book they are reading in, generally inclined to one side, in order to attain a greater degree of illumination. As they can only see distinctly objects that are near, they are obliged, by a strong effort of the mind, to cause the axes of the eyes to converge; this effort, being painful, forces them often to turn away one of their eyes, which producing double vision, they are obliged to shut it. When they hold a book directly before their eyes, the picture will fall upon the middle of the retina; but if they

hold it obliquely, it will fall upon the side of the retina; now, the middle of the retina is further from the fore part of the eye than the side of it is. Therefore, though the picture be so near to the fore part of the eye as to be confused if it fall upon the middle, it may be distinct when it falls upon the side.

As those who are very short-sighted do not perceive the motion of the eyes and features, they seldom look attentively at those with whom they are conversing: it is from this circumstance that *Pliny* terms the prominent-eyed, hebetiores; not that this defect in sight impairs genius, or lessens the powers of the mind; but as it deprives them of the rapid communications that are made by the eye, it apparently lessens that vivacity of conception, which always accompanies a vigorous mind.

Happily for the short-sighted, the principal inconveniences of their sight may be remedied by the use of concave glasses; by their assistance, those whose sphere of distinct vision scarcely extended beyond their arm, are enabled to distinguish, very satisfactorily, objects at a considerable distance; the concave lens produces distinct vision, by causing the rays to diverge more, and unite at the retina, instead of meeting before they reach the bottom of the eye.

In the choice of glasses for the short-sighted, no rules can be laid down; it is a defect that has no connection with age, no stated progression that can be a foundation to guide the optician, or lead him to recommend one glass in preference to another; the whole must depend on the observation of the short-sighted themselves, who, by trying glasses of different degrees of concavity, will soon find out that whose effects are most advantageous, producing distinct vision at different distances.

If the short-sighted person is so far removed from an optician, as not to have an opportunity of trying

a variety of lenses, he may be nearly suited, by sending to him the greatest distance, at which, with his naked eye, he can see distinctly; he will, by the following rule, be enabled to suit him with tolerable exactness.

Multiply the distance at which the short-sighted person sees distinctly with his naked eye, by the distance at which it is required he should see distinctly by a concave glass, and divide the product by the difference between the aforesaid distances: if the required distance be very remote, the glasses must be of that radius at which they see distinctly with their naked eyes.*

The benefit the short-sighted receive from concave glasses, is not so great as the long-sighted find by a convex lens; for an object is not only magnified, but the eye receives also a larger pencil of light from each visible point, because the rays enter less diverging: whereas the concave not only diminishes the object in size, but it lessens also the quantity of

* Concave glasses in the shops are generally marked from No. 1 to 17. From considerable practice in adapting them to different eyes, I have deduced the following table, supposing the common sight perfect at eight inches distance. It will be obvious, that such a table cannot be precisely true; but yet it is sufficient for a short-sighted person, having never worn glasses, or forgotten his number, to know nearly what degree of concavity he is in want of.

Distance in inches at which a fine print may be read by a short-sighted person without glasses, and the number nearly of the concave glass required.

Dist.	*Numb.*	*Dist.*	*Numb.*
8	0	$4\frac{1}{2}$	7
$7\frac{1}{2}$	1	4	8
7	2	$3\frac{1}{2}$	9
$6\frac{1}{2}$	3	3	10 to 12
6	4	$2\frac{1}{2}$	13 to 14
$5\frac{1}{2}$	5	2 to 1	15 to 17
5	6		

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light, as it renders the rays more diverging: consequently, the short-sighted do not see remote objects, unless they are very large and bright, so well through a concave lens as theory promises: for the chief impediment to a distinct view of remote objects, is their want of light and magnitude; but both of these a convex lens increases.

It is generally supposed, that the short-sighted become less so as they advance in years, as the natural shrinking and decay in the humours of the eye lessen its convexity, and thus adapt it better for viewing of distant objects; but among the great number of short-sighted that I have accommodated with glasses, I have ever found the reverse of this theory to be true, and the eyes of the myopes never required glasses less concave, but generally more concave as they grew older, to enable them to see at the same distance.

Further, the effects of habit, which are in most cases very powerful, but peculiarly so in the affections of the eye, have a natural tendency to increase the defect of the myopes; for, by frequently looking close to objects, in order to see them distinctly, they would make themselves near-sighted, though their eyes were naturally the reverse: hence we find, that watch-makers, engravers, and studious persons, often bring on this defect. By reading or working at as great a distance as possible, and often looking at remote objects, the degree of short-sightedness may be much lessened. As children in general read much nearer than grown persons, if they are suffered to indulge this propensity, they become naturally short-sighted.

I have found it necessary in some instances, to give convex glasses to the short-sighted, when very far advanced in age, not because their eyes were grown less convex, but to give them more light, and counteract an extreme contraction of the pupil.

Great as are the disadvantages of the short-sighted, they are less, perhaps, with respect to distant objects, than is generally imagined; they see the brighter stars and planets, nearly as well as other people. They are prevented indeed from distinguishing, beyond a certain small distance, the small parts of an object which are very visible to another; thus they cannot distinguish the features of a face across the room, and as objects are generally discriminated by their minuter parts, their disadvantage in viewing objects at a moderate distance is very evident. But though such a person cannot discern the minutiæ of objects, unless they are very large and very near him; yet he can perceive any object in the gross, at a considerable distance, if it be not too small: thus, he may perceive a man at the distance of several paces, but must advance within one or two, before he can determine who he is, or call him by his name; he will see a large tree much further, and, from experience in such cases, will perceive, that a large obscure object at a great distance is an house, to the surprize of his friends who are acquainted with the nature of his sight. On these principles, we may easily account for the apparent paradox of the pur-blind, or those who can scarcely see a small object at arm's length, yet discovering those that are very remote.

LECTURE XVIII.

OF THE DISTANCE, MAGNITUDE, AND APPARENT PLACE OF OBJECTS.

LET us now consider by what means the mind, assisted by the eyes, is informed of the distance of objects. Distance of itself and immediately, is imperceptible: for it is only a line directed endways to the eye. Thus, if I look endways at this piece of packthread, the length of it would be invisible from its situation, and therefore the image on the retina can only be a point, which point will be invariably the same at all distances; whether the object be a thousand miles, or only a foot from us, the point is still the same.

The change of conformation in the eye, is the first means whereby the eye judges of distance. If the figure of the eye and the situation of all its parts were to continue always the same at all distances of the objects we are looking at, the picture of some objects upon the retina would be confused, because they are too far off, and others because they are too near. In viewing objects at small but different distances, the eye must change its conformation for procuring distinct vision. Young people have commonly the power of adapting their eyes to all distances of the object, from six or seven inches to fifteen or sixteen feet, so as to have perfect and distinct vision at any distance within these limits. The effort they use to adapt the eye to any particular objects, within that distance, will become a sign of that distance.

This change in the conformation of the eye has its limits, beyond which it cannot go; it can there-

fore be of no use to us in judging of the distance of objects that are placed beyond the limits of distinct vision. But since the object appears more or less confused, according as it is more or less removed from these distances, the degree of confusion in the objects assists the mind in judging of distances, and becomes a sign thereof considerably beyond the limits of distinct vision. This confusedness has also its bounds, beyond which the image on the retina will not be sensibly more indistinct, though the object be removed to a much greater distance.

If, therefore, we had no other means but this of perceiving the distance of visible objects, the most distant would not appear to be above twenty or thirty feet from the eye; and the tops of houses and trees would seem to touch the clouds, because in that case the signs of all greater distances being the same, they have the same signification, and give the same perception of distance.

We are therefore provided with another means, namely, the inclination of the optic axes. In viewing an object attentively with both eyes, we always direct both eyes towards it, and the nearer the object is, the more they will be inclined to each other, and the more remote the less will be this inclination: and although we are not conscious of this inclination, yet we are conscious of the effort employed in it. By this means we perceive small distances more accurately than we could do by the conformation of the eye only; and therefore we find, that those who have lost the sight of one eye, are apt, even within arm's length, to make mistakes in the distance of objects, which are easily avoided by those who see with both eyes: such mistakes, as before observed, are often discovered in snuffing a candle, threading a needle, and filling a tea-cup. A person who plays well at tennis, will find himself subject to the same mistakes the first time he plays with his eyes hoodwinked.

To be convinced of the truth of this observation, suspend by a thread a ring, so that the edge may be towards you, and its aperture to the right and left; take a stick, which is crooked at the end, and retiring two or three paces from the ring, cover one eye with your hand, and endeavour with the other to pass the crooked end of the rod through the ring: easy as the experiment may appear, you will scarcely succeed once in an hundred times if you move the rod quickly.

Although this second mean of perceiving the distance of visible objects be more exact and determinate than the first, yet it hath its limits, beyond which it can be of no use. For when the optic axes directed to an object are so nearly parallel, that in directing them to an object yet more distant, we are not conscious of any new effort, nor have any different sensation; our perception of distance stops; and as all more distant objects affect the eye in the same manner, we perceive them to be at the same distance. This shews why the sun, moon, planets, and fixed stars, when not seen near the horizon, appear to be all at the same distance, as if they touched the concave surface of a great sphere.

The colours and degrees of brightness in objects is a cause of a difference of apparent distance. As objects become more and more remote, they gradually appear more faint, languid, and obscure; their minute parts become more indistinct; their outline less accurately defined; their colours not only lose their lustre, but degenerate from their natural hue, and are tinged with the azure of the intervening atmosphere. It is by these means that painters can represent upon the same canvas objects at very different distances. The diminution of magnitude in an object would not be sufficient to make it appear at a great distance without this degradation of colour, indistinctness of the outline, and of the

minute parts. If a painter should make a human figure ten times less than other human figures, that are in the same piece, having the colours as bright, and the outline and minute parts as accurately defined, it would not have the appearance of a man at a great distance, but of a pigmy or Lilliputian. Painters, therefore, to give their figures a due degree of remoteness, are obliged to lay over each a thick colouring of air; for the more remote the object, the more its own colours seem lost in that of the intervening atmosphere. This is called keeping; for by this means every object in a picture seems to keep its proper distance from the rest.

Dr. *Smith* gives us a curious observation made by Bishop *Berkeley*, in his travels through Italy and Sicily. He observed, that in those countries, cities and palaces, seen at a great distance, appeared nearer to him by several miles than they really were; and this he attributed to the purity of the Italian and Sicilian air, which gave to very distant objects that degree of brightness and distinctness, which in the grosser air of England was only seen in those that were near. Hence a chamber appears less when its walls are whitened, and fields and hills appear less when covered with snow.

It is also certain, that in air uncommonly pure, we are apt to think visible objects nearer and less than they really are, and in air uncommonly foggy we are apt to think them more distant and larger than the truth. A westerly prospect in a clear morning, with the sun upon it, appears nearer than when the sun is higher up and more westerly. The disposition of the clouds and innumerable other circumstances affect the brightness of objects, and contribute their share in forming our ideas of the distance of remote objects.

The length of the ground-plane, or a number of intervening parts perceived in it, is another mean by

which we perceive distance. We are so much accustomed to measure with the eye the ground we travel over, and to compare the judgment of distances formed by sight with actual experience or information, that we by degrees in this way form a more accurate judgment of the distance of terrestrial objects than we could do by any of the above-mentioned means.

A given extent appears longer according as it contains a greater number of visible parts; and hence two remote and very unequal distances may appear very unequal, according to the different circumstances of the intervening parts, and as the spectator is differently elevated. Thus a hedge, having in it several grown trees, generally appears longer than a clipt hedge, or the same extent of ground in an open field. For the same reason, a row of houses, columns, or trees, regularly planted, appear longer than a plain wall of the same extent; for, in this case, there are not only more visible and remarkable parts in the one case, but our pre-knowledge of the several intervening objects being equi-distant, tends to protract the apparent length of the whole chain still longer. A river at first does not look so broad as it does, after you have had a side view of the bridge across; and, indeed, a given extent of water does not appear so long as the same extent of land, it being more difficult to distinguish parts in the surface of the one, than it is in the surface of the other. Hence a person unused to a sea prospect will be much mistaken in his judgment of distances; a ship that is eight or ten miles from the shore, will scarcely seem to him to be a mile off.

When part of the intervening chain is invisible, or obscurely seen, the apparent distances of objects that are beyond that part will be accordingly less. Thus a certain extent of rough, uneven ground, appears shorter than the same extent of plane

ground; the prominent parts hiding the cavities behind them, the apparent distance is so much the less by the loss of those invisible parts. For the same reason, the brow of an hill seen over the top of another frequently looks nearer than it does after the vale between presents itself to our view; and the banks of a river at some distance will seem contiguous, if no part of the surface of the river is visible.

The known distance of the terrestrial objects which terminate our view, makes that part of the sky, which is towards the horizon, appear more distant than that which is towards the zenith. And hence the apparent figure of the sky is not that of a hemisphere, but rather a less segment of a sphere; and the diameter of the sun or moon, and the distance between two fixed stars, seen contiguous to a hill, or to any terrestrial object, appear much greater than when no such object strikes the eye at the same time.

When the visible horizon is terminated by very distant objects, the celestial vault is enlarged in all its dimensions. When viewed from a confined street or lane, it bears some proportion to the buildings which surround it; but when viewed from a large plane, terminated on all sides by hills rising one above another to the distance of twenty or more miles from the eye, you see as it were another heaven, whose magnificence declares the greatness of its Author, and puts every human edifice out of countenance; for the lofty spires and gorgeous palaces shrink into nothing before it, and bear no more proportion to the celestial dome, than their maker to its Omnipotent Maker.

Different degrees of apparent distances are suggested by the diminution of their apparent or visible magnitude. We know, by experience, what figure a man or any known object makes to our eyes at ten

feet, and we perceive a gradual diminution of the visible figure at 20, 40, 100 feet, and so on, till it at last vanishes: hence a certain visible magnitude of a known object becomes the sign of a certain determinate distance, and carries with it the conception and belief of that distance.

But when we are ignorant of the real magnitude of an object, we can never, from the apparent magnitude, form any judgment of its distance. Hence we are so frequently deceived in our estimate of distance, by the extraordinary magnitude of any object seen at the end of it; as, in travelling towards a large city, or a castle, or a cathedral church, or a large mountain, we imagine them nearer than we find them to be. This is also the reason why animals and all small objects, seen in vallies, contiguous to large mountains, appear exceedingly small; for we think the mountain nearer to us than if it were smaller, and we should be surprized at the apparent smallness of the neighbouring animals, if we thought them farther off. Hence also objects appear smaller to the eye when seen from a high building, than they seem to be when viewed from the same distance on level ground.

Let a boy, who has never been upon any high building, go to the top of St. Paul's Church, or other high edifice, and look down into the street, and the objects seen there will appear to him so small as to occasion much surprize. But ten or twenty years after, if he has now and then used himself to look from that and other great heights, the object will not appear so small. For this reason, statues placed upon very high buildings ought to be made of a larger size than those which are seen at a nearer distance.

OF APPARENT MAGNITUDE.

The apparent magnitude of very distant objects is neither determined by the angle under which they are seen, nor in the exact proportion of that angle compared with their true distance, but is compounded with a deception concerning that distance, insomuch that, if we had no idea of the difference in the distance of objects, each would appear in magnitude proportional to the angle under which it is seen; and if our apprehension of the distance was always just, our ideas of their magnitude would be in all distances unvaried; but in proportion as we err in our conception of distance, the greater angle suggests a greater magnitude. It is probable, that the apparent magnitudes are either exactly or very nearly in the compound ratio of the visual angles and apparent distance.

We are as frequently deceived in our notions of magnitude as those of distance. A fly passing before an unattentive spectator, will sometimes excite the idea of a crow flying afar off; but, as soon as the mistake in the distance is found, the crow will dwindle into a fly. Thus, also, as we have observed in foggy weather and in the dusk, objects appear further off than they really are, and in these cases proportionably larger, as there is a greater mistake in the distance. Thus a small heap of stones has been mistaken for the ruins of a large building, &c.

The diminution of apparent magnitude is so very small in proportion to the greater increase of distance, that in general the visual angles subtended by objects can have but little share in forming our judgment of their distances; and, indeed, if the case was otherwise, it would be almost impossible for us to guess aright, either as to distance or magnitude. For instance, if we did not judge indepen-

dently of the visual angle, how could we know a child from a grown person, or even a pin from a may-pole. For the largest object being removed to a greater distance may subtend an angle less than any assignable one; as objects generally appear nearer when the intervening chain is not perceived: and the same reason operates, as already observed, in making them appear proportionably smaller. Thus the distance of an object joined with its visible magnitude, is a sign of its real magnitude; and the distance of the several parts of an object joined with its visible figure, becomes a sign of its real figure.

When you look at a globe standing before you, by the original powers of sight you perceive only something of a circular form, variously coloured. The visible figure hath no distance from the eye, no convexity, nor hath it three dimensions; even its length and breadth are incapable of being measured by inches, feet, or other linear measures. But when you have learned to perceive the distance of every part of this object from the eye, this perception gives it convexity, and a spherical figure; and adds a third dimension to that which had but two before. The distance of the whole object enables you also to perceive how an inch or a foot of length affects the eye at that distance: you perceive by your eye the dimensions of the globe.

So numerous are the relations between the eye and the understanding, between light and knowledge, that there are very few parts of optics from which you may not deduce some practical advantages. Thus the judgment of the mind corresponds with the strength and colour of the objects whereon they are passed: but the further objects are removed, they grow more faint and indistinct, and of course our opinions concerning them will be less vivid and clear. Both pleasures and pains at a distance ap-

pear scarcely worth our regarding, or giving ourselves any trouble about them; the present occupies our thoughts, and forcibly carries away the preference in our imagination from the future, against the clearest and surest decisions of our understanding. To rectify this imperfection of our nature is worthy of your utmost application; and you may easily do it by gradually inuring the mental eye to discern objects at a distance. It is the quickness of this moral sense, or an habitual full persuasion of certain good and evil, however remote, being equally valuable with the present, that constitutes the virtue of prudence.

OF APPARENT MOTION.

If two objects at different distances from the eye move in parallel lines, nearly at right angles to the optic axis, and with the same velocity, the most distant will appear to move slowest, and the nearest will appear to move quickest, because the space described by the most distant object will subtend a much smaller angle to the eye.

If the directions in which the bodies move are not parallel, the nearest object may appear to move slower than the more distant, although it really moves quicker, if the space described be situated so obliquely to the visual rays, that they form at the eye much smaller angles, than smaller spaces described by the more distant object, which is exposed more directly to the eye.

If two objects unequally distant from the eye move with unequal velocities in the same direction, their apparent velocities are in a ratio compounded of the direct ratio of their true velocities, and the reciprocal one of their distances from the eye.

As objects in motion will have different apparent velocities at different distances; so to a spectator

in motion, objects at rest will have different apparent velocities. Thus a passenger in a coach sees the trees in the next hedge move swiftly backwards, while those in the field beyond move slower, and those beyond these still slower, and so on, those that are very remote being scarce perceived to move at all. And if a spectator in motion keeps his eye fixed upon an object at some distance, objects that are pretty near to it will appear at rest, whilst near objects will appear to go backwards, and more remote ones progressively forward, the same way as the spectator.

If two or more objects, having the same apparent velocity, move all the same way, an object at rest, by which they pass, may appear to move the contrary way, while the objects in motion may appear at rest: for, as their images keep the same distance upon the retina, no motion among them can be perceived. If the spectator insensibly moves his eye, so as to keep these images in the same place, the image of the object at rest will pass successively over them, in the same manner as if that object had been in motion the contrary way. The same phenomenon may happen, if the single object be in motion, either the same or the contrary way; only its apparent motion will be quicker or slower, direct or retrograde, according to different circumstances. Thus when the clouds move successively over the moon, she seems to go with their velocity the contrary way, whether that be eastward or westward.

From hence you may see how difficult it is to form a just estimate of the real velocities of objects from apparent ones, since we ought to know both the directions and distances of the moving objects, neither of which in many cases can be guessed at with tolerable accuracy.

Bodies in motion must move with a certain degree of velocity in order to become perceptible.

Though it is difficult to assign with accuracy the space that must be passed over in a given time, in order to be sensible; yet in general we may say, that it should describe, in a second of time, a space that will form at the eye an angle of fifteen or twenty seconds of a degree. Hence we may see why the heavenly bodies are not perceived to move, the spaces described by them in a minute not subtending an angle of one-fourth of a degree, when their apparent motion is greatest. For the same reason we do not perceive the motion of the hour, or even the minute hand of a watch. In the same manner a very considerable velocity, as the diurnal motion of the heavenly bodies, may be yet too slow to be perceived; and an object may move with so great a velocity as not to be perceived, as the flight of a ball out of a gun.

An object moving with great velocity is not seen unless it be very luminous. Thus a cannon ball is not seen, if it be viewed transversely; but if it be viewed according to the line it describes, it may be seen, because its picture continues long on the same place of the retina, and therefore receives a stronger impression.

As we have all been children before we were men, we have all, I doubt not, at that season, amused ourselves with many childish diversions, one of which you may remember was burning a small stick to a live coal, and whisking it round to make gold lace, as we called it. We little thought then of making experiments in philosophy; but we may turn this innocent amusement to that use, in our riper years, by gathering from hence, that our organs can continue sensation after the impulse of objects exciting it is over: for the coal is in one point only at one time, and can be seen only where it is; yet there appears an entire circle of fire, which could not happen unless the light

coming from it at every point, put the optic nerves into a motion that lasted until the object returned to the same point again; nor, unless this motion raised the same perception in the mind as it did upon the first striking of the light. For if the stick be not twirled swiftly enough, so that it cannot make a second impression from the same point, before the motion excited by the first be over, you will not see a whole fiery ring, but a lucid spot passing successively through every part of the circle.

On the principles we have laid down, are explained what are called fallacies in vision. They depend principally on our mistaking the distances of objects. Thus, parallel lines, as long vistas, consisting of parallel rows of trees, or lighted lamps by night in a long street, seem to converge more and more as they are farther extended from the eye; because the lines which measure their intervals, and which are always equal, subtend smaller angles, the more remote they are, and so appear perpetually diminishing, while we, at the same time, mistake the distance. For the same reason, the remote parts of a horizontal walk, or a long floor, will appear to ascend gradually; and the more remote the objects are that are placed upon it, the higher they will appear, till the last be seen on a level with the eye: whereas the ceiling of a long gallery appears to descend towards a horizontal line, drawn from the eye to a spectator. And the surface of the sea, seen from an eminence, seems to rise higher and higher, the farther we look: and the uppermost parts of high buildings incline forwards over the parts below; so that statues on the top of such buildings, in order to appear upright, must recline or bend backwards.

There is another phenomenon, however, not so easily accounted for: if a person turns swiftly round, without changing his place, all objects about will

seem to move round in a contrary way; and this deception continues not only while the person himself moves round, but, which is more surprizing, it continues also for some time after he ceases to move; *i. e.* when both the eye and the object are at rest. The first is not so difficult to explain, for the motion of the object on the retina easily explains it: but why it continues when both the eye and the object are at rest, has not yet been well understood. It appears to me, that the seat of sense is not altogether passive in receiving images, but positively directs a ray from itself to every object it perceives; the action and re-action between objects and the seat of sense, is wholly reciprocal. Hence we see objects, or their image, after the eye is turned from them. Hence, also, in a delirium, the objects of the imagination receive a real representation in the organs of sense: and hence we do not see an object the eye happens to be fixed on, if the attention be otherwise engaged.

It is, however, to be observed, with respect to what we call the fallacies in vision, the appearance of things to the eye always corresponds to the fixed laws of nature; therefore, to speak properly, there is no fallacy in the senses. Nature always speaks the same language, and uses the same signs, in the same circumstances: but we sometimes mistake the meaning of the signs, either through ignorance of the laws of nature, or through ignorance of the circumstances which attend the signs.

To a man unacquainted with the principle of optics, almost every experiment that is made with the prism, with the magic lanthorn, with the telescope and the microscope, seem to produce some fallacy in vision. Even the appearance of a common mirror, to one altogether unacquainted with the effects of it, would seem most remarkably fallacious: for how can a man be more imposed upon,

than in seeing that before him which is really behind him? How can he be more imposed upon, than in being made to see himself several yards removed from himself? Yet children, even before they can speak their mother-tongue, learn not to be deceived by these appearances. These, as well as all other striking appearances produced by optical glasses, are a part of the visual language; and to those who understand the laws of nature concerning light and colours, are in no wise fallacious, but have a distinct and true meaning.

OF VISION BY IMAGES.

The particular phenomena of vision, in given cases, by reflected and refracted light, have been the principal subject of the preceding Optical Lectures: but, on account of their universality, it will be proper to make a few more observations on this subject.

Vision of real objects seen directly, and vision by images, are both founded on the same principles: that is, similar impressions, or the same kind of images upon the retina, excite similar ideas in both cases. Consequently, objects, when seen by reflected or refracted rays, are seen in the places of their last images. If these images are at moderate distances before the eye, the several circumstances by which we form the ideas of the apparent distance of objects seen by naked vision, are also taken into the account. Universally, every visible point of an object appears somewhere in the direction of the axis of the pencil of rays proceeding from it to the eye after its last reflexion or refraction.

In vision by images, we are generally deprived of many circumstances by which we usually judge of distances; and this makes it difficult, in most

cases, to determine the place of an image, particularly if it be further off than two or three yards. These difficulties are frequently increased by some peculiarities appertaining to the images which we are not accustomed to, and for which we are at a loss to make proper allowances. But when the image is within the above-mentioned limits, we can, in most cases, determine its place with sufficient accuracy: and here, as well as in naked vision, the nearer we can determine the place from whence the rays converge to the eye, the more distinct will the image appear.

The apparent magnitudes of objects, seen by reflexion or refraction, are either accurately, or very nearly, as the rectangles under the visual angles and apparent distances of their last images. In all cases, the apparent place, position and figure of an object seen by refracted or reflected light, are as those of its last image. For the rays proceeding from the image to the eye, form a succession of physical points after the same manner as if they came from a real object, and therefore excite an idea of an object equal and similar to the image.

Hence, as you have seen, in vision by images, we are liable to many deceptions, some of which are entertaining as well as suprizing; for not only the place of an image, but very often its position, magnitude, and even figure, shall be quite different from the real object.

OF VISION BY IMAGES.*

As this is a subject of the greatest importance in optics, it will be worth while to consider it when

* The Rev. S. *Vince's* Plan of a Course of Lectures, p. 67.

stated in different words, with some additional circumstances.

When the rays in a pencil diverge from a point, and either by reflexion or refraction are brought all together again, they then form a luminous point corresponding to that from which they diverged.

By these means a new visible object is formed, called the image of the other; for the eye now receives the rays as coming from this latter point, and therefore judges the former point to be in the place of the latter; and as this is true for every point of any object, every object may thus actually be formed a-new, so far as regards our visible ideas. And the rays diverging to the eye from the image thus formed, in the same manner as if they came directly from the object, excite an idea of that image, or of an object similar to it.

Now, if the pencils of rays, which diverge from all points of an object, be again respectively collected at the same distances, they then form a new visible object equal to that from whence they flowed: but if the points of this new object, called the image, corresponding to those of the original object, be at a greater or less distance, they form a new visible object greater or less than the original one. Thus, therefore, we are able to form a new visible object, very near to us, exactly similar to an object at a great distance. I call this a visible object, because at the place where it is formed there is nothing to excite corresponding tangible ideas, as in the object from whence the rays first flowed. But in respect to our visible ideas, which we are here only considering, it is as much an object as the other; the eye may, therefore, be so situated with respect to this new object, that it may appear much nearer than the original object; every object appearing greater, the nearer it is to the eye.

Now, with respect to the brightness of this new visible object, we are to consider, that when the eye looks directly at any object, it receives no more rays from any one point, than what can directly enter the pupil: but, when an image is formed by a lens, for instance, all the rays from any one point of the object which fall upon the lens are collected together, and form a point of the image. Now, if the diameter of the pupil of the eye $=0.1$ inch, and the diameter of the lens be 5 inches, their areas will be as 0.01 to 25; or, as 1. to 2500: there are, therefore, *cæteris paribus*, 2500 times as many rays collected to form every point of the image by the lens, as enter the eye, and form the image, supposing all the rays to be refracted. Now although the rays diverge from every point of this image, formed by the lens, and therefore where the eye is situated it may not receive them all, yet being situated near to it, it will receive a very considerable part, and more in proportion as it is nearer.

Hence the number of rays which the eye receives from any point of this image, may be greater than that which it receives directly from the object; and thus the image may be brighter than the object. These are some of the reasons why any distant object may be made to appear larger and brighter: and the common expression, that the object is brought nearer, is not incorrect; for the visible object is actually nearer, but not being accompanied with any tangible ideas, we call it an image of the other; whereas it is a visible object formed by the same rays as the original visible object. Looking therefore at the visible object thus formed, we get an idea of the original visible object, seen under the same angle; and from thence, by association, we conclude what are the corresponding tangible ideas.

I shall conclude this Lecture on Vision with some more reflexions on the eye. They are extracted from a sermon of Mr. *Newlin*'s.

Light is truly pleasing in its own natural simplicity, and is the ornament and glory of every other object. But the eye receives it always with a fresh and increasing pleasure, as it is varied and diversified, by putting on so many sorts of colours, like so many changes of raiment.

Every time that the eye opens and expands itself, it draws as it were the whole visible world into its own narrow compass; and there is a new creation within itself. The sun, that marvellous instrument of the Most High; the moon, that shineth in the firmament of heaven; the stars, that numberless host; the rainbow, that glorious circle which is bent by the hands of the Most High; the virgin purity and unsullied whiteness of the snow; the beautiful embroidery of flowers; the rich cloathing of the meadows, and the cattle upon a thousand hills, are presented to the eye by the Lord our Maker, and set before it as on a spacious theatre.

The great source of light, which shews every thing to the eye, casts forth so bright and dazzling a lustre, that it would bear too hard upon it, and injure our visual faculty, if it were placed too near the sight; but it is fixed at so remote a distance from us, that we look upon it with pleasure, and enjoy its glory.

When the eye is wearied with its daily service, and the night spreads a veil of darkness over this lower world, the curtain that is hung before the eye falls down, and the eye-lids are shut with a close seal, till we have renewed our strength, and the morning restores the world to our view: the eye-lid not only affording refreshment and ease to the eye, but defending it from the secret perils and invisible dangers of the night.

And when day breaks, it does not shine forth at once, in full perfection, but gradually manifests itself, that the eye may not be overpowered by a sudden issuing out, and too mighty a stream of light. The sun sends a harbinger before him, to give notice of his appearance, that the dawning of the day may prepare us to receive him.

Though every colour has a peculiar beauty, yet they are not all equally agreeable and refreshing to the eye: but the verdure of the fields is most particularly pleasing to it, and we can bear to dwell the longest upon it: God has appointed it for the common dress of nature, and made this colour the most familiar to our sight. He leads us through the green pastures, and adorns the herbs and plants with many varieties, even in the same colour, and changes it every day.

Time would fail me, even in attempting to describe all the pleasures and advantages of sight. I cannot, however, leave the subject without one or two observations. The eyes are a faithful guard to the whole man, and are placed as in a friendly watch-tower, to discern his danger, and give him friendly warning, while it is yet afar off.

The eye is instrumental in promoting the happiness of conversation. It is the eye that meets our friend with joy, and kindles and imparts the heavenly flame of friendship. It is the eye that pities and spares, and yearns over the miserable object with generous compassion. It was with the eye that our Saviour reproved St. *Peter*. O Lord, how marvellous are thy works! in wisdom hast thou made them all! The eye that sees, gives witness of thee; and the ear that hears, confirms its testimony.

LECTURE XIX.

OF COLOURS.

No philosophical subject is more worthy of your attention than light; it is the means by which all the beauties and glories of the creation are laid open to view. With some of its curious properties you are well acquainted; a new scene will now rise before you equally admirable with those that have preceded.

I have hitherto considered light as a body uncompounded, and of parts resembling each other; but we are going to examine its texture more closely. You will now see that this fluid, so simple in appearance, is made up of very different particles; that it is composed of very different coloured teints; and that from the nature of this composition arises that charming variety of shades which paints the face of nature.

Whatever pleasures we derive from the beauty of colouring, we owe it to the different rays of light, each object sending back to our eyes those rays, which its surface is best adapted to reflect: in this sense the blushing beauties of the rose, and the modest blue of the violet, may be considered as not in the objects themselves, but in the light that adorns them. Odour, softness, and beauty of figure, are their own; but it is light which dresses them up in those robes which shame the monarch's glory.

Natural philosophers were formerly of opinion, that the solar light was simple and uniform, without any difference or variety in its parts, and that the different colours of objects were made by refraction, reflexion, or shadows. But *Newton* taught them the errors of their former opinions; he shewed them to

dissect a single ray of light with the minutest precision, and demonstrated that every ray was itself a composition of several rays all of different colours, each of which when separate held to its own nature, simple and unchanged by every experiment that could be tried upon it. Or to be more particular, light is not all similar and homogeneal, but compounded of heterogeneal and dissimilar rays, some of which in like instances being more refrangible, and others less refrangible; and those which are most refrangible are also most reflexible: and according as they differ in refrangibility and reflexibility, they are endowed with the power of exciting in us sensations of different colours.

Newton's theory of light and colours is striking and beautiful in itself, and deduced from clear and decisive experiments, and may be almost said to demonstrate clearly,

1st. That lights which differ in colour, differ also in degrees of refrangibility.

2d. That the light of the sun, notwithstanding its uniform appearance, consists of rays differently refrangible.

3d. That those rays which are more refrangible than others, are also more reflexible.

4th. That as the rays of light differ in degrees of refrangibility and reflexibility, so they also differ in their disposition to exhibit this or that particular colour; and that colours are not qualifications of light, derived from refractions or reflexions of natural bodies, as was generally believed, but original and connate properties, which are different in different rays, some rays being disposed to exhibit a red colour and no other, and some a green and no other; and so of the rest of the prismatic colours.

5th. That the light of the sun consists of *violet* making, *indigo* making, *blue* making, *green* making, *yellow* making, *orange* making, and *red* making rays;

and all of these are different in their degrees of refrangibility and reflexibility; for the rays which produce red colours are the least refrangible, and those that make the violet the most; and the rest are more or less refrangible as they approach either of these extremes, in the order already mentioned: that is, orange is least refrangible next to red, yellow next to orange, and so on; so that to the same degree of refrangibility, there ever belongs the same colour, and to the same colour the same degree of refrangibility.

6th. Every homogeneal ray, considered apart, is refracted according to one and the same rule, so that its sine of incidence is to its sine of refraction in a given ratio; that is, every different coloured ray has a different ratio belonging to it.

7th. The species of colour, and degree of refrangibility and reflexibility, proper to any particular sort of rays, is not mutable by reflexion or refraction from natural bodies, nor by any other cause that has been yet observed. When any one kind of rays has been separated from those of other kinds, it has obstinately retained its colours, notwithstanding all endeavours to bring about a change.

8th. Yet seeming transmutations of colours may be made, where there is any mixture of divers sorts of rays; for, in such mixtures, the component colours appear not, but by their mutually alloying each other, constitute an intermediate colour.

9th. There are, therefore, two sorts of colour, the one original and simple, the other compounded of these; and all the colours in the universe are either the colours of homogeneal, simple light, or compounded of these mixed together in certain proportions. The colours of simple light are, as we observed before, violet, indigo, blue, green, yellow, orange, and red, together with an indefinite variety of intermediate gradations. The colours of com-

pounded light are differently compounded of these simple rays, mixed in various proportions: thus a mixture of yellow-making and blue-making rays exhibit a green colour, and a mixture of red and yellow makes an orange; and in any colour, the same in specie with the primary ones, may be produced by the composition of the two colours next adjacent in the series of colours generated by the prism, whereof the one is next most refrangible, and the other next least refrangible. But this is not the case with those that are situated at too great a distance; orange and indigo do not produce the intermediate green, nor scarlet and green the intermediate yellow.

10th. The most curious and wonderful composition of light, is that of *whiteness*; there is no one sort of rays which can alone exhibit the colour, it is ever compounded, and to its composition all the aforesaid primary colours are requisite.

11th. As whiteness is produced by a copious reflexion of rays of all sorts of colours, when there is a due proportion in the mixture; so, on the contrary, *blackness* is produced by a suffocation and absorption of the incident light, which being stopped and suppressed in the black body, is not reflected outward, but reflected and refracted within the body till it be stifled and lost.

Having thus endeavoured to give you a general idea of the theory of colours, I shall proceed to explain the subject more fully, illustrating it by the experiments so admirably devised by *Newton*. The sun shines favourably for our purpose, we will therefore go into the darkened room; I have been, you see, particularly careful to exclude all light from the room, but what enters through the tube I have fixed in the window-shutter. I admit a beam of light through a hole in this tube of about one-quarter of an inch diameter; the beam darts through the

hole, and forms on the floor an image of the sun nearly circular. I now place my glass prism so as to receive the beam of light, and you observe how beautifully that beam is refracted into different coloured rays. The cylindric beam of light passes into the prism, is there dilated, and by refraction thrown into an oblong form, exhibiting on the opposite side of the room an amazing bright and beautiful spectrum of colours. The prism is triangular at each end, about six inches long, and is polished on the three sides. I have placed it parallel to the horizon, with its axis perpendicular to the beam of light. On turning the prism slowly about its axis, you see that the refracted light on the wall, or the coloured image of the sun, first descends, and then ascends; between the ascent and descent, that is, where the image is stationary, the prism is to be fixed, because in that situation the refractions of the light on the two sides are equal to one another. A prism mounted on a brass stand, with a ball and socket, or other universal joint, is for convenience to be preferred.

Whenever you would have the refractions on both sides of the prism to be equal, you must note the place on the wall where the image is quiescent, or the mean point between two contrary motions, and there fix the prism. I shall make all the following experiments with the prism in this situation, unless some other position be mentioned.

The refracted light falls perpendicularly upon a sheet of white paper, placed on the opposite wall of the chamber, where an oblong, not an oval, image of the solar spot is formed; it is terminated by two rectilineal and parallel sides, and two semicircular ends; the sides are better defined than the ends, which are confused and indistinct, because the light at the ends decays and vanishes by degrees.

The lower extremity is red, above this is placed

the orange, afterwards the yellow, then the green, the blue, the indigo, and lastly the violet, which is placed in the upper part of the image. There are, you see, innumerable gradations connecting and uniting the primary one, each colour gradually degenerating as it were into the succeeding one. You will not always be able to distinguish clearly the whole seven colours, as it requires a very excellent prism, and great attention and accuracy in performing the experiment, to prevent some of those which most nearly resemble each other from being confounded together: you will, however, scarce ever fail in seeing five distinctly marked, the lower red gradually declining into a yellow, the yellow succeeded by an intense green, above this a bright and lovely blue, and then a soft but glorious mazarine or violet colour.

The breadth of the spectrum answers to the breadth of the sun's circular image. If the prism had a smaller angle, the length of the image would be less. If I turn the prism so that the rays emerge more obliquely, the image soon becomes an inch or two longer; but if I turn it about the contrary way, so as to make the rays fall more obliquely on the side nearest the hole, it soon becomes an inch or two shorter: therefore, in repeating this experiment, you should be careful so to place the prism that the refraction on both sides may be alike.

This experiment is represented in *plate* 6, *fig*. 9. T, the tube through which the sun's beam enters the room, in the direction T o I, but is turned out of this direction by a glass prism SPD, whose axis is perpendicular to the beam; by this the rays of light are refracted so as to form a beautiful coloured spectrum, M N, upon the screen, K L. The most refrangible rays being thrown to M furthest from I, but the least refrangible being turned less out of their course, fall upon a part of the screen N, and nearest I, while those that are unfrangible in the

intermediate degrees will fall between M and N, forming, instead of a circular space, a long spectrum bounded by right-lined sides, and circular ends, and whose length is at right angles to the direction of the axis of the prism.

The size of the hole in the window-shutter, the different thickness of the prism through which the rays pass, the different inclinations of the prism to the horizon, and the various altitudes of the sun, make no sensible change in the length of the image, nor is it affected by the different matter of which the prism is formed, With a prism, whose refracting angle is $62\frac{1}{2}^{\circ}$ at $18\frac{1}{2}$ feet from the prism, the length of the image is about $9\frac{3}{4}$ or ten inches.*

If the rays were equally refrangible, that is, equally inclined to the surface of the prism in the ingress and egress, their direction would be only changed; the image would be a circle, which will appear sufficiently clear by your considering these diagrams. Let A B C, *plate* 6, *fig*. 8, be a section of a triangular prism at right angles to its axis. Suppose J N to be a ray incident at N, and thence refracted to E, on the surface C B, where it is again refracted into the situation E M. Let *i n* be another ray, parallel to the former, and consequently incident at *n* with the same angle.

Now if the ray, *i n*, has exactly the same capability or disposition to be refracted by the prism, as the ray J N, the angles of refraction will be also equal, and *i n* will, when refracted into the directions n e and e m, still continue parallel to the ray J N, which is refracted into N E and E M.

But if it be more refrangible, it will be refracted into other directions, as n f, f g, verging more to-

* As the rays of the sun are not always to be obtained, I have prepared a small model with coloured silk strings, similar to those exhibited in Lecture XVII. to shew the nature and proportion of the coloured rays issuing from a glass prism.

wards the base, AC; or, if it be less refrangible, it will be refracted into directions, as nh and hk, that verge less towards the base AC.

Whence it appears, that if a collection or pencil of rays fall parallel to each other on one of the sides of a prism, and do not proceed parallel to each other on their emergence, it must be because some of the rays are more refrangible than others.

The preceding experiment therefore with the prism proves, *that the sun's light is composed of rays whose refrangibilities are not all the same*; for after emerging from the prism, instead of illuminating a circular space, they are spread into a long spectrum, bounded by right-lined sides and circular ends, and whose length is at right angles to the axis of the prism.

Turn the prism, which is so placed that the axis is perpendicular to the beam of light, that the image may be stationary, and there fix it; this being done, look through the prism at the hole, the length of the image will appear to be many times greater than the breadth; the most refracted part being violet, and the least refracted red; the middle parts blue, green, yellow, &c. in order.

Now remove the prism out of the sun-beam, and look through it at the hole, and you will have the same appearance; if all the rays were equally refracted, the hole would appear round when refracted through the prism. This, therefore, like the preceding experiment, proves, that at equal incidences there is a considerable inequality of refraction. Besides the different refrangibility, the foregoing experiments shew also another remarkable difference between the rays; namely, *that the different refrangibility of the rays is joined with a difference in colour; and all the rays, as they are more or less bent by refraction, have a colour peculiar to themselves.*

To render this subject clearer, and to shew that these appearances are not accidental, but inherent properties of light, Sir *Isaac Newton* tried what would be the effect of refracting the rays of light a second time: for this purpose, he let the light refracted by the first prism fall upon a second prism, placed at about one foot from the first; the first prism was in an horizontal, the second in a vertical situation. An image was formed by the second prism, similar both in the arrangement of colours and its dimensions, to that in the first experiment, with this only difference, that it was not now in a vertical, but in an inclined position. Now if the effects were only caused by a modification of light produced by the prism, the second ought to form in breadth the image that the former made in length, and thus produce a square spectrum, which is contrary to the fact. The inclination of the spectrum is solely occasioned by the unequal refrangibility; those rays that were most bent by the first prism, being so also by the second; the upper part in both prisms suffering a greater refraction, and the lower part a less refraction; likewise, as before, the upper part appears violet, and the lower part red.

At *plate* 6, *fig*. 10, is a diagram to illustrate this experiment. AB represents the second prism in a vertical direction, that it may again refract the rays which come from the first. By the first prism the rays are refracted upwards; by the second, sideways; by the first it is refracted to *m n*, while M N is the image formed by the refraction of the two cross prisms. The breadth of the image is not increased, the upper part suffers a greater refraction, and the lower a less one in both prisms.

If a third, and even a fourth prism be placed in the same manner after the second, the result will be the same; and the most refrangible rays will still be

most refracted, and the least the least refracted, whilst their colours remain unchanged.

Let us now proceed to another experiment. Here, as in the first, the light is transmitted through a prism, but the coloured image is received on a screen which I have placed in the middle of the room; there is a hole in the screen, through which the rays of any single colour may be suffered to pass alone, by raising or lowering the screen. Thus for instance, I place the hole against the blue part of the image, so that none but the blue rays go through it; these are again refracted by a prism: now you see that the blue rays, after having passed through the prism, continue the same as before, without any manner of alteration, forming a blue image on the opposite side of the wall, and the figure of this image is circular. The direction of the beam is altered, but the rays are not dilated or separated into different sorts, as the common beam of light was by the first prism. I now move the screen to the yellow rays, and you observe that these rays falling on the second prism are refracted to the side of the room, and there form only a yellow spot, and the same with the rest of the colours; so that none of these colours are changed by refraction. Further, if you place any small bodies in these circular images, they will appear of the same colour with the image, red in the red light, green in the green light, &c. so that the colours are no ways changed by reflexion. Again, if you look at any of these spots through a prism, they still preserve their colour, and are not expanded or dilated in length; so that homogeneal light suffers no manner of alteration in any case.

In all the trials that have been made, it appears, that those rays which are most refracted at first, are always most refracted; and those that are least at first, are always least afterwards. It is therefore

plain, *that every ray of light has a peculiar degree of refrangibility, which cannot be changed by any reflexions or refractions, but remains constantly and invariably the same.*

The different refrangibility of the rays of light is a cause of confusion in bodies seen through a refracting medium; for this will occasion the different rays flowing from the same point, to be refracted to different points on the retina. Thus, small objects placed in a sun-beam, and viewed through a prism, will be seen but confusedly; but if they are placed in a beam of homogeneous light, separated by a prism, they will appear as distinct through a prism, as when viewed by the naked eye.

As the light reflected from all terrestrial bodies is the solar light, we may fairly conclude from the foregoing experiments, that *the light reflected or emitted from all bodies, consists of rays differently refrangible:* and this may be further proved, for if you look at any object through a prism, that object will appear tinged with colours. Take a small part of a body, illuminate it strongly, and look at it through a prism, and you will have an oblong image with all the colours; a star, a lamp, a candle, a burning coal, a red-hot iron, or any burning matter seen through a prism, will present you with the same appearances.

If you are desirous of seeing a complete specimen of analytical reasoning, you should read Sir *Isaac Newton*'s Optics, where you will find him pursuing this subject in a variety of ways; putting nature to a thousand proofs, in order to establish his deductions on a sure foundation. It is impossible for me to give you even an imperfect idea of this method in these Lectures; it will be sufficient if you here attain so much knowledge as will awaken your attention to a fuller and closer investigation of the subject. Having shewn you by the preceding experi-

ments, that the light of the sun consists of rays differently refrangible, I shall now endeavour to prove to you, that *the rays of light which differ in colour, differ also in refrangibility.*

It is not indeed always necessary that judgment should be founded on demonstration in order to obtain your confidence, for demonstration is rarely to be found. It is expedient, therefore, to study the art of judging accurately upon probabilities, which, where they can be clearly discerned, are sufficient grounds for confidence, until new light break in, or circumstances change, whereon a new judgment may be formed with similar accuracy. It is the vain expectation of absolute certainty that keeps many continually wavering and irresolute; for, being afraid of trusting to any thing that has not such certainty, and being able to find it no where, they live in a round of doubts, without being able to settle on any one point. You may be assured, that some courage, as well as caution, is requisite, either to secure freedom of thought, or open a passage to proficiency in any science.

Here is an oblong piece of paper, one half of which is coloured strongly with red, the other with blue; place it upon this piece of black cloth near the window, where it will be strongly illuminated; now look at it through a glass prism held parallel to it and to the horizon, with the refracting angle upwards, the paper will appear broken and divided into two parts, the blue half is lifted higher by refraction than the red. If you turn the refracting angle of the prism downwards, so that the paper may be carried lower by refraction, the blue half will be carried lower than the red half. This experiment shews clearly, that the light from the blue is more refracted, and is therefore more refrangible than the light from the red.

I shall now wrap a thread of black silk several times round a piece of paper, one half of which is coloured like that we used in the preceding experiment, and the thread appears as if it were so many black lines drawn upon the colours. Darken the room, and set the paper up perpendicularly against the wall, so that one of the colours may stand to the right, the other to the left; now illuminate it strongly with a candle, while with a lens of a long focus, I collect the rays, so as to form an image of the coloured paper upon the white screen, the screen being at about the same distance from the lens as the lens is from the coloured paper.

Move the screen backwards and forwards to find where the images of the blue and red parts of the paper are most distinct; this is easily known by the images of the black threads of silk, and you will find that where the red half appears distinct, the blue half is confused; and, on the contrary, when the blue half appear distinct, the red is so confused, that the black lines are scarcely visible: the space between these two situations of the paper is about an inch and an half, the distance of the paper from the lens being about six feet. The focal distance of the red rays being longer than that of the blue, is a proof that the blue rays are more refrangible than the red; and we obtain a new demonstration of the difference in the refrangiblity from the different focal distances, at which the rays proceed from different colours; for those whose rays are most refrangible must be collected and united at the shortest distance. Therefore, rays that differ in their colour differ also in their degrees of refrangibility.

The different refrangibility of the rays of light is a great obstacle to the perfection of telescopes and microscopes. This is a clear inference from our last experiment, for no rays issuing from a point can be refracted by a lens to a single point.

From what has been said it is also plain, that if the solar light consisted but of one kind of rays, there would be but one colour in the world; or, in other words, all things would be of the same colour.

From one experiment to another, Sir *Isaac Newton* was led to what he justly calls the *experimentum crucis*, which I shall relate to you so as to enable you to repeat it at your leisure, as we have already employed as much of our time as can be well spared on the subject. He took two thin boards, and placed one of them close behind the prism at the window, in such a manner that the middle of the refracted light might pass through the hole made in it, and the rest be intercepted by the board, and be refracted on the other board, which he placed at about the distance of twelve feet; having made a small hole in the second board also, and placed it in such manner that the middle of refracted light, which came through the hole in the first, might pass through that of the second, the rest being intercepted by the board might paint upon it the coloured spectrum of the sun.

He then placed another prism behind the second board, so that the light which was transmitted through both the boards might pass through that also, and be again refracted before it arrived at the wall.

This being done, he took the first prism in his hand, and turned it about its axis, so as to make the several parts of the image, cast on the second board, to pass successively through the hole therein, and fall upon the prism behind it, that he might observe to what places on the wall they would be refracted by the second prism; and it appeared, that the light which was most refracted by the first prism was also most refracted by the second, and went to the higher part of the wall; and the

light, which was least refracted by the first, was also least refracted by the second; and that the most refrangible was violet, and the least so red. During the experiment, the two boards and the second prism remained unmoved, by which means the incidence thereon was always the same; so that without any difference in the medium some of them shall be more refracted than others; and that according to their different degrees of refrangibility they will be transmitted through the prism to different parts of the wall.

Plate 6, *fig.* 11, V S T is the prism that first receives the solar light; this is refracted and falls upon the middle of the board P X Q, the middle part of which falls upon the second board *p x q*. By turning the prism, VST, slowly forwards and backwards about its axis, the image will be made to move up and down, so that all the parts from one end to the other may be made to pass successively through the hole *x*. *a s t*, another prism placed to refract the light passing through the hole, *x*, on the screen Y Z *y*. The position of the holes remaining constantly the same, the incidence of the rays on the second prism was the same in all cases; yet with that common incidence some rays are more refracted, and others less.

The rays of light that fall on a reflecting surface in the same angle, if reflected at all, are reflected in the same angles; consequently, there will be no such separation in degree of the rays of light by reflexion as there is by refraction. This position is readily proved. I shall place this plane mirror in an horizontal position, so as to receive this beam from the hole in the window-shutter, and it is thereby, you see, reflected to the opposite wall; the figure of the reflected light is circular like the hole, but there is no separation of the rays as in refraction, nor any colours produced by reflexion; the rays, which have

the same incidence, running parallel to one another after reflexion, being reflected at equal angles: though the most refrangible will be the soonest reflected, if they move out of a dense into a rare medium; a circumstance which does not in the least affect the present proposition.

The rays of the sun's light, however, which are refrangible, are also more reflexible than others. L K I, *plate* 6, *fig*. 12, represents a prism; the angle, K, is a right angle; the other angles, L, I, are 45° or equal to each other; T M, a beam of light that passes through the surface K I, and is incident at M, upon L I. It will emerge in the direction M S; but when the angle of incidence at M is such, that the sine of the angle of refraction is equal to the radius, the angle of refraction becoming a right one, the ray cannot emerge, but will be wholly reflected.

By turning the prism slowly about its axis until all the light which went through one of its angles, and was refracted by it, began to be reflected by its base, Sir *Isaac Newton* found, that those rays which had suffered the greatest refraction were sooner reflected than the rest; he therefore conceived, that those rays of reflected light, which were the most refrangible, did first of all, by a total reflexion, become more copious in that light than the rest; and that afterwards the rest also, by a total reflexion, became as copious as these. To try this, he made the reflected ray, *plate* 6, *fig*. 12, pass through another prism T V X, so placed as to separate its component colours by refraction; then in the reflected beam, O M, the rays which first begin to be reflected, consisting almost entirely of violet light, were by the second prism so refracted as to fall on q, and paint a violet colour. As the first prism continues to be turned on its axis, the light is more and more copiously reflected, and the colours between q and r appear in succession till the red ap-

pears, when the reflexion becoming total, the colours formed by refraction at Q R S disappear, as those at q s appear.

In the beginning of this Lecture I observed to you, that no one kind of ray would exhibit whiteness; it is the most surprizing and wonderful composition, an assemblage of all the colours of the prism in union. *Whiteness, or the solar light, is always compounded; and all the primary colours mixed in due proportion, are requisite to its formation.* I shall illustrate this by one of the most celebrated, and most simple of Sir *Isaac Newton*'s experiments.

I darken again our room, and, as in the first experiment, refract a beam of light by a prism, and receive its image on the screen. Let us remove the screen, and hold this lens, so that the refracted rays may fall upon it; this, you perceive, has occasioned the coloured light, which diverged from the prism, to unite and meet again at its focus; and you have upon a piece of paper held behind the solar image intensely coloured: the rays have no sooner, you see, passed through the lens, than they begin to mix and efface each other, and lose the fine harmonious proportion that was before exhibited in the spaces of the coloured image. As you remove the paper from the lens, the colours will approach more and more to each other, and by mixing together will be more and more diluted. You are now at the focus, and, you see, they are perfectly mixed together, the colours wholly vanish, and are converted into whiteness, they forming a small circular image totally white; the red no longer displays its lively flame, the green boasts no more the livery of the spring, nor the blue the lucid robe of heaven, but all blended together exhibit the whiteness of the sun, from whence they proceeded. Remove the paper still further back, so as to receive the rays after having crossed at the focus, and as

they diverge you see they again renew their splendour and colour, but in a contrary order, the red being now above, and the violet below. This reappearance of the colours beyond the place where they are blended, is a further proof of the immutability of the primary colours, as it shews that they neither lose their colour or quality by being blended or intersecting each other, and that the whiteness which appears is produced only by their mixture.

The whiteness is made up of all the colours of the image; for, if any of the rays be intercepted in their passage, the whiteness ceases, and degenerates into that colour which arises from the composition of those which were not intercepted, but suffered to pass through the lens; and if the intercepted colour be again let pass, and fall upon the compound, it will immediately restore its whiteness.

That in forming the white, the rays do not suffer change by acting on each other, is clear; for if you hold the paper beyond the focus of the lens, and stop the red colour, the violet suffers no change; nor will the violet be changed by stopping the red, and letting the violet pass.

When the paper is held at the focus, if you look through a prism at the white circular image, you will have a coloured spectrum; let any ray be intercepted while the image is thus examined, and then let it pass again, and the colour will appear and disappear as often as you repeat the experiment, the remaining colours not suffering any change; clearly shewing, that one colour depends on one kind of rays, and another colour on another kind. So replete and decisive are the experiments of Sir *Isaac Newton*, that they not only prove the proposition they were primarily invented to illustrate, but at the same time they also strengthen the truth of other propositions.

Convincing as were these experiments, the fertile imagination of *Newton* invented new ones, which, though different from each other, all concurred to prove the same thing; they seemed to rise under his hands, as the poets make flowers spring under the feet of their beauties.* He caused an instrument to be made in the form of a comb, with teeth an inch and an half broad, and at two inches distance from each other; by passing this comb over the lens, placed as in the last experiment, part of the colours were intercepted by the teeth, while the rest proceeded on to the paper, placed at the focus of the lens. This image appeared white when the comb was taken away, but when this was interposed the whiteness was changed into the colour passing through the comb. When the motion of the comb is slow, the colours, red, yellow, green, blue purple, always succeed one another; but when the comb is moved quickly, the colours following one another with extreme rapidity, cannot be distinguished, and from the confusion of the whole there arises one uniform colour; the impression of all the colours is at once in the same part of the eye, and they jointly excite the sensation of whiteness.

Here is a common boy's spinning top; the surface is divided and painted into certain proportions, to accord with the coloured spectrum of the prism; by pulling this string I shall make the top revolve rapidly on its axis; while it is so revolving you can distinguish none of the colours singly, but the whole appears white, and this whiteness will be greater in proportion as the particular colours are brighter.

The colours produced by the prism are not only the most beautiful in nature, but each in itself con-

* *Algarotti*'s Philosophy of *Newton* Explained.

tinues separate and unalterable. When one of these primitive rays has been separated from the rest, nothing can change its colour; send it through other prisms, refract or reflect it, still it remains unalterable, the red ray preserves its crimson, and the violet its purple beauty. *Whatever object falls under any of them soon gives up its own colour, though ever so vivid, to assume the homogeneal light of the prismatic ray.* Take a piece of paper, and place it in the red-making ray, and it will appear red; place it in the other coloured rays, and you will always find it assume the radial colour. Take a piece of coloured paper, and put it in the red light, and it will appear red; hold it in the yellow, orange, &c. and it will appear yellow, orange, &c. respectively. In short, no art can alter the colour of a separated ray; it gives teint to every object, but will assume none from any; neither reflexion, refraction, nor any other means, can make it forego its native hue; like gold, it may be tried by every experiment, but will still come forth the same.

It will be necessary here to explain the method used by Sir *Isaac Newton*, to define the boundaries of each colour in the prismatic spectrum. You observed in the image, that though there was a manifest difference of colour not only between the two extremes, but also in the intermediate parts, yet the exact place at which any one colour ended and another began was far from being sufficiently distinguishable; this indistinctness was occasioned by rays of every kind, proceeding from all parts of the sun's disk; an entire image of the sun is projected on the paper, consisting of a circle of each particular colour: and as the rays differ in kind by infinitesimal degrees, from the extreme red to the extreme violet, there must, in fact, be thousands of these circles in the oblong image, the centers of which are infinitely

near to each other, so that the light is intimately mixed, especially in the middle of the image, where it is brightest.

He therefore considered, that if these circles could be made less, while their centers kept the same distance and positions, their interference and mixture with each other would be proportionably diminished; and that they would be so diminished, if without the room at a great distance from the prism, towards the sun, an opake body were interposed, having a round hole in the middle of it, to intercept all the sun's light, except as much as coming from the middle of its disk could pass through that hole to the prism; for then the separate circles would no longer answer to the whole disk of the sun, but only to that part of it which can be seen from the prism through that hole. But to make these circles answer more distinctly to the hole, a lens is to be placed by the prism, to cast the image of the hole, that is, of each separate circle distinctly on the paper.

At about ten or twelve feet from the window Sir *Isaac Newton* placed a lens, by which the image of the hole might be distinctly cast upon a sheet of paper at six, eight, ten, or twelve feet from the lens. Immediately after the lens he placed a prism, by which the reflected light might be thrown upwards or sideways; moving the paper that received the image nearer to or further from the prism, till he found the situation, where the sides of the image were, more distinct.

Plate 6, *fig*. 13, F is the hole in the window-shutter; M N a lens, whereby the image of that hole is cast distinctly on the paper at I; A B C a prism to refract the rays, emerging from the lens to another paper at *p t*; the round image, at I, is thereby turned into an oblong image, *p t*, falling on the other paper. The image, *p t*, consists of circles

placed one after another in rectilinear order, the circles are equal in magnitude to the circle I; consequently, by diminishing the hole F, they may be at pleasure diminished, whilst their centers remain in their places. By this means, the breadth of the image, *p t*, may be made forty times, and sometimes sixty or seventy times less than its length, and thereby the mixture of the rays as much or as little as you please.

By this means he obtained a distinct termination of the images of the hole without any penumbra, and therefore only extending the least degree into each other, and consequently there was very little mixture of heterogeneal rays. By enlarging or diminishing the hole in the window-shutter, he made the circular images greater or less at pleasure, and thereby the mixture of rays in the oblong image was as much or as little as he chose; sometimes making the image forty times, and sometimes sixty or seventy times less than its length.

Thus the light was rendered sufficiently simple for trying any of his experiments about homogeneal light, the heterogeneous rays being so few as hardly to be perceived, excepting in the indigo and violet, which being dark colours easily suffer an allay, even by the little scattering light refracted irregularly by the inequalities of the prism.

When he had thus got the sides of the coloured image distinctly defined, he delineated the outlines of it on paper, holding the paper so that the image might fall on the paper, and coincide with it exactly; while an assistant marked the confines of each colour, by lines drawn across the image. This was frequently repeated, both on the same and different papers; the observations were found to agree well enough with each other, and the sides were divided like a musical chord, and were in proportion to one another, as the numbers 1, $\frac{8}{9}$, $\frac{5}{6}$, $\frac{3}{4}$, $\frac{2}{3}$, $\frac{1}{5}$, $\frac{3}{16}$, and $\frac{1}{2}$, and

so represented the chords of the key, and of a tone, a third minor, a fourth, a fifth, a sixth major, a seventh, and an eighth above that key.

The length of the spaces, which the seven primary colours possess in the spectrum, exactly corresponds to those of the chords that sound the seven notes in the diatonic scale of music.

From this reasoning, colours and sounds have been thought to be, in some respect, similar. There are seven notes in music; there are also so many primary colours: the distance between each note is ascertained; a similar distance is also found between each coloured ray. But the diversities between them are more numerous than the similitudes. The combination of tones increases their beauty; but the combination of colours deadens their effect. The succession of sounds has a wonderful influence on the mind; the succession of colours has scarce any. Notwithstanding this, *Pere Castel* has written a treatise, to prove that as the ear finds pleasure in the succession of sounds; so the eye may have a similar one from the succession of colours. For this purpose, he constructed an ocular harpsichord, which, instead of sounding to the ear, presented colours to the eye: the prismatic rays furnished the notes, and the shades between were substituted for the semitones. Sounds furnish the ear with all its pleasures, but colours furnish the eye but with half its pleasure; therefore little is to be expected from the music of colours. To make such an instrument satisfy the sense of sight, the beauty of figure must be united to that of colour.

The foregoing principles account for several phenomena, that were inexplicable before Sir *Isaac Newton* had investigated the theory of colours. Among others, why, upon looking at any object through a prism, the edges only appeared tinged with colours, and that in a certain order. Thus, when you look

through a prism at any object, if not too small, particularly if it be white, the edges only of the object are coloured; one edge red, orange, and yellow; the other blue, indigo, and violet. These colours are the extremities of so many images of the object, as there are rays of light differently refrangible. This will be best explained by a diagram. Let A B C D, *plate* 6, *fig.* 17, be a white figure, viewed through a prism H I K; C E, D E, are rays proceeding from the extremities, which, if the prism were not interposed, would meet at E; but by means of the prism, are unequally refracted; the red uniting in G, the violet at F; the intermediate one between G and F, into as many points as there are rays differently refrangible. The eye being situated so as to receive these rays, sees, in this refracted direction, the image, *a o s p*, augmented in height, by the quantity *b o*, which is that of the rays, separated by refraction. The edges of this image are coloured; the lower edge red, from *a* to *c*; orange, from *c* to *d*; and yellow, between *d* and *e*. At the upper edge, blue, from *l* to *m*; indigo, from *m* to *n*; violet from *n* to *o*. From what we have said, it is easy for you to perceive, that these colours are the extremities of so many images of the object; each colour occupying a space, equal in extent to that of the card A B C D, which receives the light of the sun, which light is composed of all the rays. The red image, therefore, extends from *a* to *b*; the orange, from *c* to *i*; the yellow, from *d* to *k*; the green, from *e* to *l*; the blue, from *f* to *m*; the indigo, from *g* to *n*; the violet, from *h* to *o*.

This explains clearly, why the extremities only are coloured, while the middle remains white; the colours anticipate one on the other, so that they are all mixed together in the space between *h* and *b*; in the small intervals between *e* and *h*, and *b* and *l*, it is nearly white. It is only from *a* to *e*, and from *l* to *o*,

that the colours are sufficiently pure and unmixed, to be apparent.

If the object you look at through the prism is small, and viewed at a distance, the whole surface is coloured; for when the object is small, each object occupies less space; whilst the quantity that the rays are separated from each other, is the same, they are consequently less mixed, and more apparent.

If a black object be surrounded with a white one, the colours which are perceived, are to be derived from the light of the illuminated object spreading into the regions of the black; and therefore they appear in a contrary order to what they do when a white object is surrounded with a black one.

It is the same when an object is viewed, the parts of which are less luminous than others; for, in the borders of the more or less luminous parts, colours ought always to arise from the same principle, viz. from the excess of light of the more luminous object, and to be of the same kind as if the darker parts were black, but yet to be more faint and dilute.

What is said of colours made by prisms, may be easily applied to the colours made by the glasses of telescopes and microscopes, or by the humours of the eye; for, if the object-glass of a telescope be thicker on one side than the other, or if one half of the glass, or one half of the pupil of the eye, be covered with any opake substance, the object-glass, or that part of it or of the eye which is not covered, may be considered as a wedge with crooked sides: and every other pellucid substance has the effect of a prism, in refracting the light that passes through its substance.

Though the foregoing theory of light and colour was first fully and clearly investigated by Sir *Isaac Newton*, yet some traces thereof are to be found among the ancients.

Plato does not seem to have been altogether ignorant of the Newtonian system of colours; for he calls them the effect of light transmitted from bodies, the particles of which were adapted to the organs of sight. Now this is precisely the same with what Sir *Isaac* teaches, "that the different sensations of each particular colour are excited in us by the difference of size in those small particles of light which form the several rays; those small particles of light occasioning different images of colour, as the vibration is more or less lively with which they strike our senses." *Plato* hath gone further: he has entered into a detail of the composition of colours, and inquired into the visible effects that must arise from a mixture of the different rays of which light itself is composed. He thought certain rules might be laid down on this subject, if, in following and imitating nature, we could arrive at the art of forming a diversity of colours by the combined intermixture of others; adding afterwards what may be considered as the noblest eulogium ever made on Sir *Isaac Newton*. "Should ever any one," exclaims this sublime philosopher of antiquity, "attempt, by curious research, to account for this admirable mechanism, he will, in doing so, but manifest how entirely ignorant he is of the difference between divine and human power. It is true, God can intermingle those things one with another, and then sever them at his pleasure: because he is, at the same time, all knowing and all powerful: but there is no man now exists, nor ever will, perhaps, who shall ever be able to accomplish things so very difficult." What an eulogium are these words in the mouth of such a philosopher as *Plato*, and how glorious is he who hath successfully accomplished what appeared impracticable to that prince of philosophers! And what an elevation of genius, what

piercing penetration into the most intimate secrets of nature, displays itself even in the passages recited from *Plato*, when we consider that philosophy was then but in its infancy.

LECTURE XX.

OF THE RAINBOW.

When we look back upon the knowledge of the several periods of time with which history has left us any acquaintance, and compare it with the present, reviewing at the same time the improvements of the two last centuries, and compare them with the whole series of what preceded, we can scarce avoid regarding the later period with a respect that approaches to veneration.

It is not to be doubted, but that men have at all times the same natural abilities. That many of the sages of antiquity were men of the greatest ability, and most extensive genius, they have left sufficient evidence in the records of their works. The glory of the present period is, that genius and application have been directed into a proper course, that men have studied things instead of words, and have built their systems upon facts, not, like their predecessors, on theories.

I would not be understood as desirous of taking from the venerable fathers of erudition all claim to useful discoveries; for their writings give us testimony of inventions which the most enterprizing geniuses of these ages have found it impossible to equal; but these are few. With us knowledge is the offspring of experiment, and we advance nothing

as a principle, but what is in a degree demonstrable, and what can be in some way put to the test of experience. On this stable foundation science has risen to its present height, a situation in which the most sanguine of the writers in the obscurer ages could never have expected to see it; and yet far below that degree of perfection to which I think it possible it may arrive, and to which by these very means it may be carried. It is not easy to say what will be the triumphs of modern application joined to modern genius, nor to say where it will stop, while there is the same ardour in the pursuit, the same principles to work upon, and an infinite number of facts ascertained.

The colours of the rainbow, which struck antiquity with amazement, no longer now create the philosopher's surprize. To *Pliny* and *Plutarch* it appeared as an object which we might admire, but could never explain. *Kepler* seems to have been the first, who supposed that it might arise from the refraction of the sun's rays upon entering the rain drops. *Antonio de Dominis* enlarged a theory just hinted at by *Kepler*. Each succeeding philosopher went on in improving a theory, the truth of which seemed to carry a great probability; but as they were ignorant of the true causes of colour, they left the task unfinished for *Newton* to complete. You will find, that the theory of the rainbow, as explained by him, is full, clear, and will impress your mind with perfect conviction.

Of the various meteors the rainbow is one of the most pleasing; its colours not only delight the eye with the mildness of their lustre, but encourage the spectator with the prospect of succeeding serenity. It is almost needless to describe this meteor, as there are very few but must have surveyed it with pleasure and surprize. You know that it is only seen when the spectator turns his back to the sun,

and when it rains on the opposite side. Its colours, beginning from the under part, are violet, indigo, blue, green, yellow, orange, red, so that it contains all the beautiful and simple shades of the prism; without the first, there is often an external rainbow, whose colours are less vivid and ranged in an opposite order, beginning from the under part, red, orange, yellow, green, blue, indigo, violet. Sometimes we see half, sometimes an whole bow; frequently one, very often two, nay three have been seen. Though the rainbow is generally formed by the reflexion of the rays of the sun's light, from the drops of falling rain, it frequently appears among the waves of the sea, whose heads or tops are blown by the wind into small drops; it is also sometimes to be seen on the ground, when the sun shines on a very thick dew. Cascades and fountains, whose waters in their fall are divided into drops, will exhibit rainbows to a spectator, properly situated, during the time of the sun's shining. This appearance is also seen by moon-light, though seldom vivid enough to render the colours distinguishable; and an artificial rainbow may even be produced by candle-light on the water, which is ejected by a small fountain, or jet d'eau.* All these are of the same nature, and dependent on the same causes, some idea of which may be formed by considering these diagrams.

Let the circle *s t* D, *plate* 7, *fig.* 12, and *g d s*, *fig.* 13, represent two drops of water; S *s*, *fig.* 12, a ray of light falling obliquely on the drop of water at *s*, instead of continuing in its direction towards F, is refracted to *t*, whence it will be in part reflected to *e*, making the angle of incidence equal to the angle of reflexion, where, instead of going on di-

* But the most natural and pleasing is by means of the air-fountain, placed in the sun's rays, which the reader will see described in vol. i. page 135. Edit.

rectly to *f*, it will be again refracted by passing obliquely out of the water into the air.

But as this ray of light consists of a pencil of rays, some of which are more refrangible than the others, the violet, which is most so, will proceed towards B, and the red, which is the least, towards O. If then the eye of the spectator be so placed at O, that the ray of light falling upon it from the drop of water has been once reflected and twice refracted, so that *e* O shall make with the solar ray *s* S an angle S F O of 42° 2′, he will see the red ray in the direction *e r*; for it has been found by computation, that the greatest angle, under which the most refrangible rays, after one reflexion, can come to the eye of a spectator, is 40° 17′; and that the greatest angle under which the least refrangible rays come to the eye is 42° 2′.

If the eye be afterwards raised to B, so that the ray, *e b*, forms with the solar ray only an angle of 40° 17′, he will see the violet ray in the direction *b* B, and the intermediate colours at intermediate directions. The same thing takes place if, the eye of the spectator remaining in the same space O, the drop of water descends from D to E; or if you suppose this space filled with drops of water, you will then see at the same time all the prismatic colours. The rays which have the intermediate degrees of refrangibility will come most copiously from drops between D and E, and exhibit the intermediate colours in the order which their degree of refrangibility requires.

Now what has been said of one globe or drop of water, is true of millions of drops. Let us now imagine a number of such drops of rain, placed in the circumference of a semicircle, in the center of which is the eye of the spectator, and we shall have a semicircular band, adorned with the seven primitive colours, and whose breadth will be equal

to D E, that is, in proportion to the difference between the most and least refrangible rays.

To explain the exterior bow, let us suppose a ray of light S *s*, *fig.* 13, from the sun, falling obliquely on a drop of water, represented by the circle *g d s*; instead of continuing in its original direction to *a*, it is refracted to *d*, from whence it will be in part reflected to *e*; falling again on the concave surface, a part will be again reflected towards *g*, where it will pass into the air again, and be refracted a second time. This ray of light, like the preceding, will be now decomposed; the red, which is the least refrangible, will proceed to O; and the violet, which is the most so, to B. Now an eye situated at O, so as to receive the ray of light, which having been twice refracted and twice reflected by the drops of water, makes with the solar ray an angle, S *h* O, of 50° 55′, will see the red in the direction O *r*; if the eye is lowered to B, so that the angle, S *h* B, is 54° 7′, it will perceive the violet ray; and in proceeding from O to B, all the prismatic colours successively.

It has been found, that the smallest angle under which the least refrangible rays can come to the eye after two reflexions is 50° 7′, and that the smallest angle under which the most refrangible can come is 54° 7′. Hence, if the sun were a point, the diameter of the exterior bow would be 3° 10′, and that of the interior bow 1° 45′, and the distance between them 8° 55′; but as his body subtends an angle of 32′ 5″, each bow will be increased by that quantity, and their reciprocal distance diminished.

The same effects would take place if the eye of the observer were fixed at O, and the drop of water ascended from G to H; or, if you suppose this space filled up with drops of water, all the prismatic colours will be seen at the same time, the drops between G H striking the sense with the intermediate

colours, in the order of their refrangibility. If, as in the preceding case, you imagine a series of such drops situated in the circumference of a semicircle, in whose center is the eye of the spectator, you will have a second semicircle, enriched with seven primitive colours, but in contrary order to the first bow. Thus there will be formed two bows of colours, an interior and stronger by one reflexion in the drops, and an exterior and fainter by two reflexions, the light becoming fainter by every reflexion: their colours will be in a contrary order to each other, the red of both bows bordering upon the space which is between the bows.

What has been here only supposed, really takes place when the rain falls; so that when the rain and the sun, with regard to the spectator's horizon, are in opposite parts of the heaven, there is a sufficient number of drops in a proper situation for the emergent rays to form with the incident rays the angles necessary to produce a rainbow. Let E, F, G, H, *plate* 7, *fig.* 14, represent drops of rain, on which the solar rays S E, S F, S G, S H, are incident; these rays, after having been twice refracted at E and F, and once reflected, fall upon the eye at O. The angle, S E O, formed by the incident ray S E, and the emergent ray, E O, being 40° 17′, the violet colour will be perceived at E; the angle, S F O, formed in the same manner by the incident ray S F, and the emergent ray F O, being 42° 2′, the red is perceived at F; the drops of rain between E and F, sending to the eye the necessary emergent ray for producing the intermediate colours.

Thus also the rays S G, S H, after two refractions and two reflexions, are also directed towards the eye placed at O. The angle S G O, formed by the incident ray S G, and the emergent ray G O, being 50° 57′, the red is seen at G; the angle S H O, formed by the incident ray S H, and the emergent

ray, H O, being 54° 7′, the violet is seen at H, the other drops of rain which are between G and H, furnish the intermediate colours. The same may be said of the rest of the drops constituting the two semicircular bands A F B E, C H D G.

This may be illustrated by experiment, for if the rays of light fall on the surface of a glass sphere filled with water, they will be refracted to the other side, and there exhibit a coloured spot of refracted light; from this part, the rays will be reflected to another part of the lower surface, and there be refracted a second time into the air, and dilated into all the different coloured rays, so that if a person's eye was placed under such a globe, he would observe all the different colours appear in that globe. For this purpose, here is a globe filled with water, which I shall suspend in a sun-beam, at such a height that you may easily observe this phenomenon. You see it now receives the light on the upper part, refracts it from the lower into all its different coloured rays, forming thereby a circle of coloured light on the floor much resembling the rainbow. Now, if you place yourself in such manner respecting the globe, that the rays of light of different colours may successively fall upon the eye, then you will see all those colours in the globe which before formed the variagated arc upon the floor.

This is a case exactly similar to the rainbow; for if this globe of water was placed in the heavens, it is evident that the sun-beams would be refracted through it as they are here.

To illustrate the nature of the second bow, we must let the sun-beam fall upon the lower part of the globe; you see plainly the coloured spot behind, to which it is refracted; cast your eye on the upper part, and you perceive the point to which it is reflected, from whence it is a second time reflected to the fore part of the globe; and from thence you see

it a second time refracted out of the globe into the air, and the beam thereby dissipated into all its different coloured rays; and you see by the colours on the floor, that the several rays in the beam lie in a different order from what they did when refracted from the globe before: and also you will perceive, that the colours of the beam are more dilute and faint than they were in the first experiment.

It was by this experiment that *Antonio de Dominis* undertook to explain the cause of the rainbow. Filling a glass globe with water, hung at a certain height opposite to the sun, and standing himself with his back to the sun and his face to the globe, he found, when this was in such a situation, that a ray darting from the sun to the globe made an angle with another ray going from his eye to the globe of 42° 3′, he found the globe appeared red. If the position of the globe was altered, so as to make the angle between the solar and visual ray less, then the other colours of the rainbow arose from red down to violet, which appeared at an angle of 40° 17′.

You will now be able to account for all the phenomena of the rainbow; it appears always of the same breadth, because the degrees of refrangibility of the red and violet rays, which form the extreme rays, are always the same. The rainbow forms a greater or smaller portion of a circle. Our eye is a point of a cone, and the rays that proceed from it at the above-mentioned angles form the surface of the cone; the coloured circle is the base, part of which is visible, while the earth cuts off the part which lies below the horizon. The portion in view is of course greater or smaller, as the line of sight is more or less inclined to the horizon; this obliquity increases in proportion to the elevation of the sun; consequently the size of the bow diminishes as the altitude of the sun increases. To make this plainer, suppose the

spectator on the top of a very high mountain, and the rain falling at some little distance from him, instead of a semicircular rainbow he would then see a complete ring of that beautiful meteor; a circle not like our common bow, cut off by the earth, but complete and beautiful; and such is usually seen from the American Andes.

From hence we see why there is no rainbow, when the sun is above a certain altitude; the conical surface under which it becomes visible being below the horizon, when the altitude of the sun is more than 42 degrees; if the altitude is more than 42, but less than 54, the exterior bow may be visible, though the interior bow is invisible. Sometimes the rain does not occupy a space extensive enough to complete the bow, only a portion of an arc will in such cases be visible; and the appearance of this portion, and even the bow itself, will be various, according to the nature of the situation and the space occupied by the rain.

OF THE SEPARATION OF THE ORIGINAL RAYS OF LIGHT BY REFLEXION OR TRANSMISSION, BUT DEPENDING ON THE THICKNESS OF THE MEDIUM UPON WHICH THEY ARE INCIDENT.

The foundation of a rational theory being laid, it next became natural to inquire by what peculiar mechanism in the structure of each particular body, it was fitted to reflect one kind of rays more than another. This Sir *Isaac Newton* attributes to the density of these bodies. This subject is not so clear as the preceding; the present theory suggests many doubts to every inquisitive mind, and is allowed by all to be attended with difficulties. There are no optical experiments, however, in which Sir *Isaac Newton* seems to have taken more pains, than those relating to the rings of colours which appear in thin

plates, and which I am going to explain to you; in all his observations and investigations concerning them, he discovers the greatest sagacity, both as a philosopher and a mathematician.

The bubbles which children blow with a mixture of soap and water, were observed by Dr. *Hooke* to exhibit various colours according to their thinness, and that when they have a considerable degree of thickness, they appear colourless; from this the present theory has taken its rise. It is thus that things, overlooked by the rest of mankind, are often the most fertile in suggesting hints to those who are habituated to reflexion.

Sir *Isaac Newton* blew up a large bubble from a strong mixture of soap and water, and set himself attentively to consider the different changes of colour it underwent, from its enlargement to its dissolution. He in general perceived that the thinner the plate of water which composed the sides of the bubble, the more it reflected the violet colour ray; and that in proportion as the sides of the bubble were more thick and dense, the more they reflected the red: he therefore was induced to believe, that the colours of all bodies proceeded from the thickness and density of the little transparent plates of which they are composed. To bring this opinion nearer to certainty, it was necessary to measure the thickness of the plate of water which composed the bubble; but this was a matter of great difficulty, as the bubble was of itself of too transient a nature to undergo the necessary experiments.

Sir *Isaac*, who was ever fertile in expedients, recollected having observed, that as two prisms were compressed hard together, in order to make their sides (which happened to be a little convex) touch one another, they were both as perfectly transparent in the place of contact as if they had been but one piece of glass; but that round the point of contact,

where the glasses were a little separated from each other, rings of different colours appeared.

To observe more accurately the order of the colours produced in this manner, he placed a glass lens, whose convexity was very small, upon a plane glass. Now it is evident, that those would only touch at one particular point; and therefore, at all other places between the adjacent surfaces, a thin plate of air was interposed, whose thickness increased in a certain ratio, according to the distance from the point of contact.

He pressed these glasses slowly together, by which means the colours very soon emerged, and appeared distinct to a considerable distance; next to the pellucid central spot made by the contact of the glasses, succeeded blue, yellow, white, yellow and red. The blue was very little in quantity, nor could he discern any violet in it; but the yellow and red were very copious extending about as far as the white, and four or five times as far as the blue. The next circuit immediately surrounding these consisted of violet, blue, green, yellow, and red; all these were very copious except the green, which was very little in quantity, and seemed more faint and dilute than the other colours. The third circle of colours was purple, blue, green, yellow, and red; in this the purple was more reddish than the violet in the former circuit, and the green was more conspicuous, being as bright and copious as any of the other colours, except the yellow; the red was also somewhat faded. The fourth circle consisted of green and red; the green was copious and lively, inclining on one side to blue, on the other to yellow, but there was neither violet, blue, nor yellow; and the red was very imperfect and dirty. Each outer circuit or ring was more obscure than those within, like the circular waves upon a disturbed sheet of water, till they at last ended in perfect whiteness.

As the colours were thus found to vary according to the different distances of the glass plates from each other, Sir *Isaac* judged that they proceeded from the different thickness of the plate of air intercepted between the glasses; and that this plate was, by the mere circumstance of thinness or thickness, disposed to reflect or transmit this or that particular colour; from whence he concluded, as before observed, that the colours of all natural bodies depended on their component particles. He also constructed a table, wherein the thickness of a plate necessary to reflect any particular colour, was expressed in parts of an inch, divided into 1,000,000 parts.

The appearance of these circles, when the glasses were most compressed, so as to make the black spot appear in the center, is delineated *plate* 7, *fig*. 15, where a, b, c, d, e; f, g, h, i, k; l, m, n, o, p; q, r; s, t; u, x; y, z, denote the colours reckoned in order from the center, *viz*. black, blue, green, yellow, red, purple, blue, green, yellow, red; green, red; greenish blue, red; greenish blue, reddish white.

I have already observed to you, that the thin plates, made use of in the former experiments, reflected some kinds of rays in particular parts, and transmitted others in the same parts. Hence the coloured rings appeared variously disposed, according as they were viewed by reflected or transmitted light; that is, according as the plates were or were not held up between the eye and the window. That you may understand this better, here is a table, on one side of which are mentioned the colours appearing on the plates by reflected light, and on the other, those which were perceived when the glasses were held between the eye and the window. The center, when the glasses were in full contact, was perfectly transparent; this spot, therefore, when viewed by reflected light, appeared black, because

it transmitted all the rays; and for the same reason it appeared white, when viewed by transmitted light.

Colours by reflected light.	*Colours by transmitted light*
Black	White
Blue	Yellowish red
White	Black
Yellow	Violet
Red	Blue
Violet	White
Blue	Yellow
Green	Red
Yellow	Violet
Red	Blue
Purple	Green
Blue	Yellow
Green	Red
Yellow	Bluish green
Red	
Green	Red
Red	Bluish green
Greenish blue	Red
Red	

In comparing the rings produced by transmitted with those produced by reflected light, the white was found opposed to the black, the red to the blue, the yellow to the violet, and the green to a colour composed of red and violet; in other words, the parts of the glass that, when looked at, where white, appeared black on looking through the glass; on the contrary, those which appeared black in the first instance, appeared white in the second; and so of the other colours: which you will more readily comprehend by considering this figure, where AB, CD, *plate* 7, *fig*. 17, represent the glasses which touch at E; the black lines traced between them are the distances between the two surfaces, at different

distances from the center, each distance answering to a coloured ring; the colours written above are those seen by reflected light; those underneath, are the colours exhibited by transmitted light. *Newton* has shewn, that the rays of any particular colour are disposed to be reflected, when the thicknesses of the plate of air are as the numbers 1, 3, 5, 7, 9, 11, &c. and that the same rays are disposed to be transmitted at the intermediate thicknesses, which are as the numbers 0, 2, 4, 6, 8, 10, &c.

The places of reflexion or transmission of the several colours in a series, are so near each other, that the colours dilute each other by mixture; whence the number of series, in the open day-light, seldom exceeds seven or eight. But if the system be viewed through a prism, by which means the rings of various colours are separated according to their refrangibility, they may be seen on that side towards which the refraction is made, so numerous that it is impossible to enumerate them. Or, if in a dark chamber the sun's light be separated into its original rays by a prism, and a ray of one uncompounded colour be received upon the two glasses, the number of circles will become very numerous, and both the reflected and transmitted light will remain of the same colour as the original incident ray. This experiment shews that in any series, the circles formed by the less refrangible rays exceed in magnitude those which are formed by the more refrangible; and, consequently, that in any series the more refrangible rays are reflected at less thicknesses than those which are less refrangible.

Water applied to the edges of the glass, is attracted between them; and, filling all the intercedent space, becomes a thin plate of the same dimensions as that which before was constituted of air: in this case, the circular rings grew less, and the colours were fainter, but not varied in species. They were

contracted in diameter, nearly in proportion of seven to eight, and, consequently, the intervals of the glasses at similar circles, as caused by these two mediums, are as about three to four; that is, as the sines of refraction out of water into air.

I have already mentioned to you the variety of colours produced by bubbles blown in soap-water; but, as these colours are commonly too much agitated by the external air to admit of any certain observation, it is necessary to cover thr bubble with a clear glass,* in which situation you will find the following appearances: the colours emerge from the top of the bubble, and as it grows thinner, by the subsidence of the water, they dilate into rings parallel to the horizon, which descend slowly, and vanish successively at the bottom. This emergence continues till the water at the upper part of the bubble becomes too thin to reflect the light, at which time a circle of intense blackness appears at the top, which slowly dilates, sometimes to three quarters of an inch in breadth, before the bubble breaks. Reckoning from the black central spot, the reflected colours are the same, in succession and quality, as those produced by the afore-mentioned plate of air; and the appearance of the bubble, if viewed by transmitted light, is similar to that of the plate of air in like circumstances.

Take very thin plates of talc, or Muscovy glass, that exhibit these colours; then, by wetting the plates, the colours remain as before, but become more faint and languid, especially when wetted on the under side. So that the thickness of any plate requisite to produce any colour, seems to depend only on the density of the plate, not on the density

* *Nicholson*'s Introduction to Philosophy, vol. i. p. 283.

of the inclosing medium. But the colours are more vivid, as their densities are different.

If two pieces of plate glass, or even common glass, be previously wiped, and then rubbed together, they will soon adhere with a considerable degree of force, and exhibit various ranges of colours, much broader than those obtained by lenses. One of the most remarkable circumstances attending this method of making the experiment, is the facility with which the colours may be removed, or even made to disappear, by heats too low to separate the glasses. A touch of the finger immediately causes the irregular rings of colours to contract towards their center, in the part touched.

From these experiments it appears plain, that the colours of bodies depend, in some degree, upon the thickness and density of the particles that compose them.

Hence, if the density, or size of the particles in the surface of a body be changed, the colour is likewise changed.

When the thickness of the particles of a body is such, that one sort of light or one sort of colour is reflected, another light or other colours will be transmitted; and therefore the body will appear of the first colour.

A certain determinate thickness seems to be necessary in a plate of water; for example, in order to reflect a particular colour, and a different thickness, to make it reflect any other colour; and, in general, that a less thickness is necessary to reflect the most refrangible rays, as violet and indigo, than those which are least refrangible, as red and orange.

The particles of bodies reflect rays of one colour, and transmit those of another: and this is the ground of all their colours.

OF THE TRANSIENT STATE INTO WHICH A RAY OF LIGHT IS PUT IN ITS PASSAGE THROUGH ANY REFRACTING SURFACE, WHICH, IN THE PROGRESS OF THE RAY, RETURNS AT EQUAL INTERVALS; AND DISPOSES THE RAY AT EVERY RETURN TO BE TRANSMITTED, AND BETWEEN THE RETURNS, TO BE REFLECTED TO IT.

In order to account for the intervals of the coloured rings in these thin plates, and also all other cases of the reflexion or transmission of light, Sir *Isaac Newton* advances an hypothesis; but, like a wise man and cautious philosopher, he professes not to lay much stress upon it, though he seems not to entertain any suspicion of its truth. Indeed, it seems to be a kind of fair inference from the preceding experiments.

The hypothesis is this: that every ray of light is, at its first emission from the luminous body, put into a transient state or constitution, which in its progress returns at equal intervals, disposing it at every return, to be easily transmitted into any refracting surface it may meet with; whereas, in the intervals between these returns, it is disposed to be easily reflected; so that, upon the arrival of a number of rays of light at the surface of every medium, those of them in which they were disposed to be transmitted easily, would pass the interval between the two mediums, and those which were in a contrary state would be reflected; on which account, some light is generally reflected and some transmitted, at every different surface on which it falls. Those states into which the rays of light are put, he calls *fits of easy reflexion and transmission.*

This hypothesis is not without difficulties, and must, therefore, be received with caution, as it was proposed, till it shall be either confirmed or con-

futed by experiments, and a new theory substituted in its place.

When arrived, as it were, at the confines of material nature, you must expect to meet with some confusion and darkness in our explanations. There are barriers to our knowledge, which cannot be passed by any force of human faculties. Sir *Isaac Newton*, the legislator of philosophers, expressed under the form of conjectures or questions, those things which he was unable satisfactorily to resolve; avoiding rash assertions, which are so fondly taken up by those who wish to seduce mankind.

He conjectured, that these fits of easy reflexion and transmission may be occasioned by the vibrations of a subtile fluid, in which the ray passes; any ray being disposed to be transmitted when the vibration coincides with it, and to be reflected when it is thereby counteracted.

He also thought that these vibrations might be excited by the mutual action and re-action of light of bodies, and of this medium, at the instant of refraction and reflexion.

Sir *Isaac*, therefore, supposed two causes of this disposition to be reflected or transmitted, when rays of light arrive at any new surface. One of them is the regular vibration of the etherial medium, affecting them through the whole of their progress from the luminous body; and the other the tremulous motion, or irregular vibration of the same medium at the surfaces of bodies, occasioned by the action and re-action between those bodies and light.

Thus, as stones, by falling into water, put the water into an undulating motion; and all bodies, by percussion, excite vibrations in the air; so the rays of light, by impinging on any refracting or reflecting surface, excite vibrations in the refracting or reflecting medium; and by exciting these, agitate the solid parts of the refracting or reflecting body;

and that the vibrations thus excited in this subtile refracting or reflecting medium, are propagated much after the manner that vibrations are propagated in the air, causing sound, and moving faster than the rays, so as to overtake them; and that when any ray is in that part of the vibration which conspires with its motion, it easily breaks through a refracting surface; but when it is in a contrary part of the vibration, which impedes its motion, it is easily reflected; and, by consequence, that every ray is successively disposed to be easily reflected, or easily transmitted by every vibration by which it is overtaken.

OF THE PERMANENT COLOURS OF NATURAL BODIES, AND OF THE ANALOGY BETWEEN THEM AND THE COLOURS OF THIN TRANSPARENT PLATES.

You have already seen, that the colours of natural bodies consist in a disposition to reflect one sort of rays more copiously than another; and that other bodies are of a different colour, because they reflect rays of a different kind. So that if light consisted only of one kind of rays, there could be only one colour in the world; nor would it be possible, by refractions and reflexions, to produce a new one. Thus, in some bodies, all the rays are extinguished by the red-making, and when they are reflected to our eyes, they excite in us the idea of red; and thence we say, that such a piece of cloth, &c. is red; attributing that only to the cloth or wood, which more particularly arises from the light which dresses them in their various beauty. Thus the ruby absorbs the green, the blue, and the violet; but reflects the red-making rays to our eye, with all their prismatic lustre. The amathyst imbibes the stronger

rays, and gives back the violet with milder brightness. The jonquil gives us only yellow, and the hyacinth its vivid blue. Every coloured object may be thus regarded as a partial divider of the rays, separating one or more colours, and confounding all the rest.

Those surfaces of transparent bodies, which have the greatest refracting power, reflect the greatest quantity of light. In other words, bodies, by which the light is more refracted, do likewise more strongly reflect it. Diamonds, which refract the light very strongly, give it, in proportion, a stronger reflexion: hence proceed the vivacity of their colours and their sparkling lustre.

The analogy between refraction and reflexion will appear by considering, that the most refractive medium totally reflects the rays of light, at certain degrees of incidence. But the truth of the proposition further appears, by observing the transparent bodies, such as air, water, oil, glass. Island crystal, white transparent arsenic, and diamond, have a stronger or weaker reflexion, according to the greater or less refractive powers of the mediums that are contiguous to them. Thus at the confine of air and sal gem, it is stronger than at the confine of air and water; and still stronger between common air and glass; still more so between air and a diamond. If any of these be immersed in water, its reflexion becomes weaker than before; and it is weaker still, if it be immersed in liquors of a greater refractive power. If water be divided into two parts, by any imaginary surface, there is no reflexion at the confines of those two parts; and for the same reason, there can be no sensible reflexion in the confine of two glasses of equal density. The reason, therefore, why all pellucid mediums have no sensible reflexion but at their external surfaces, where they

are contiguous to mediums of different densities, is, that their contiguous parts have precisely the same degree of density.

The least parts of all bodies, though seemingly void of transparency, when viewed in the gross, will be found, if taken separately, to be, in some measure, transparent: and the opacity arises from the multitude of reflexions caused in their internal parts. This observation will be easily granted by those who have been conversant with microscopes; for there they are found to be, for the most part, transparent. Nothing seems more opake, and free from transparency than the cloathes you wear. Yet let us only examine one of the woollen hairs that go into its composition, with a microscope, and you will find it to be nearly transparent. Gold, in the mass, lets no light pass through it; but if beaten out extremely thin, we shall then see that its parts are transparent, like other bodies. If held over a hole in a darkened window, it will appear of a greenish hue. If gold be composed of transparent parts, we may surely conclude the same of other bodies: and, indeed, you will find very few which, if reduced to sufficient thinness, and applied to the hole, but what are manifestly transparent.

Since light finds a free passage through the least particles, we are to inquire what renders them opake; and this, by Sir *Isaac Newton*, is attributed to the multitude of reflexions and refractions which take place in its interior parts; there being, between the parts of opake or coloured bodies, a number of spaces, filled with mediums of a different density from that of the body, as water between the tinging corpuscles with which any liquor is impregnated; air between the aqueous globules that constitute clouds and mists. These spaces cannot be traversed by light, without refracting or reflecting it

in various ways, by which it is prevented from passing on in a straight line, which it would do if the parts were continuous, without any such interstices between them; for you have already learned, that reflexions are only made at the superficies of mediums of different densities. The opacity of bodies arises, therefore, from the discontinuity of its particles, and the different density of the intervening mediums, and their particles.

This notion of opacity is greatly confirmed by considering, that opake bodies become transparent by filling up the pores with any substance of nearly the same density with their parts. Thus when paper is wet with oil or water, or when linen cloth is dipped in water, oiled, or varnished, or the oculus mundi steeped in water, &c. they become more transparent than they were before: as filling the pores of an opake body makes it transparent, so, on the other hand, evacuating the pores of a transparent body, or separating its parts, renders it opake; as salts, or wet paper, by being dried; horn, by being scraped; glass, by being reduced to powder, or otherwise flawed; turpentine, by being stirred about with water, till they mix imperfectly; and water, by being formed into many small bubbles, either in the form of froth, or, by shaking it together with oil of turpentine, or some other convenient liquor, with which it will not incorporate.

Hence, then, it is in homogeneity you are to seek for the cause of transparency. If there be many pores in a body, and these be filled with a matter differing much in density from the body itself, the light will meet with a thousand refractions and reflexions in the internal parts, and will thus be utterly extinguished.

The parts of bodies, and their interstices, must not be less than some definite size, to become opake and coloured.

For the most opake bodies, if their parts be sufficiently divided, as metals, by being dissolved in acid menstrua, &c. become perfectly transparent. And you may remember, that the black spot, near the point of contact of the two plates of glass, transmitted the whole light where the glasses did not absolutely touch; and the reflexion at the thinnest part of the soap was so insensible as to make that part appear intensely black, by the want of reflected light.

On these grounds it is, that water, salt, glass, stones, &c. are transparent, for, from many considerations, they seem to be as full of pores as other bodies are, yet their particles and pores are too small to cause reflexion in their common surfaces.

The transparent parts of bodies, according to their several sizes, must reflect rays of one colour, and transmit those of others, on the same principles that thin plates or bubbles do reflect or transmit these rays; and this seems to be the ground of all their colours.

That they do so, is plain from various observations; and it is on these principles you may explain the variety of colours seen in some silks, on pigeons necks, peacocks tails, and the feathers of other finely coloured birds. If you fix your eye upon a pigeon's neck, and both be kept at rest, only one colour is observable: but if either moves, especially the latter, a different colour may be seen. Shady silks are woven with threads of different colours; one arranged longitudinally, the other transversely; and as the greater or less proportion of either of these appears, so one or other of the colours will prevail. Wet these double coloured objects, dip the variegated feather in water, or the changeable silk in oil, their reflexions will be less vivid, and they will return but one uniform shade

of colouring. The skin of the camelion is transparent, its ground being between a pale red and yellow, coloured with a number of small, smooth protuberances of cold, bluish colour. It is endowed with a faculty of blowing up or contracting its skin at will. This causes the different colours, in appearance, to vary: it, therefore, sometimes appears reddish, at others, blue: the yellow rays of the ground, occasionally mixing with the blue of the protuberances, produces the idea of the green; and when placed on a red or yellow substance, its natural colours are unavoidably heightened.

It is evident, from various phenomena, that a great proportion of the fainter coloured rays are stopped in their passage through the atmosphere, and are thence reflected upon other bodies; while the red and orange rays are transmitted to greater distances. This circumstance explains the blue shadows of bodies, the blue colour of the sky, and the red colour of the clouds, when the sun is near the horizon.

At certain times, when the sky is clear and serene, in the morning and the evening, the shadows cast from opake bodies have been observed to be tinged with blue and green. This circumstance naturally results from the minute particles of the atmosphere reflecting the delicate and most refrangible rays, the blue and violet, for instance; which occasions a predominance of these colours.

The blue colour of the sky is accounted for on the same principles; namely, the copious reflexion of the blue rays, by the atmosphere, which produces the effect of an arc of that colour, all around us. This is occasionally diversified by the vapours density, which reflect the stronger rays.

The coloured clouds, in particular, which appear towards the morning and evening, when the sun is in or near the horizon, are to be attributed to the

same cause. The rays of light traversing a vast extent of the atmosphere; the fainter and more delicate rays, as the blue and violet, are detached by repeated reflexions of the atmospheric particles; and the stronger rays, as the red, the orange, &c. are permitted to proceed, and reach the clouds, from whence they are reflected. Agreeable to this theory, you may observe, that the sun's horizontal light is sometimes so deeply tinctured with the red, that objects illuminated by it frequently appear of a bright orange, and even red. It is observable, that the clouds do not, in common, assume their brighter dyes till the sun is some minutes set, and that they pass from a yellow to a flaming gold colour; and thence, by degrees, to red, which becomes deeper and deeper, till the sun leaves them altogether, till at length the disappearance of the sun leaves them of a leaden hue, by the reflexion of the blue light from the air. A similar change of colour is observed on the snowy top of the Alps; and the same may be seen, though less strongly, on the eastern and western fronts of white buildings: St. Paul's church, London, is a good object of this kind, and is often, at sun-set, tinged with a considerable degree of redness. What makes the same colours more rich and copious in the clouds, is their semi-transparency, joined with the obliquity of their situation.

It is probably the same coloured light, which being thrown, by the refraction of the atmosphere, into the shadow of the earth, sometimes gives the moon, in a total eclipse, the obscure, reddish colour of brick. For the same reason, the colour of the moon will vary in eclipses, according to the extent of the atmosphere the rays have to traverse.

MR. DELAVAL'S ACCOUNT OF THE PERMANENT COLOURS OF OPAKE BODIES.

I should leave this subject very incomplete, if I did not give you some account of the ingenious observations of Mr. *Delaval,* extracted from a paper communicated by him to the Literary and Philosophical Society of Manchester, and published in the second volume of their memoirs.*

Mr. *Delaval* was led to this subject, from a persuasion of its utility to those interesting and elegant arts, whose object is the preparation and use of colouring substances: justly observing, that our views of experimental philosophy should not be confined to theory alone, but directed also to its practical application.

For, in proportion as the principles of any science are unknown or misconceived, the advancement of the arts and manufactures which depend on them, must, of course, be impeded; for, without those guides, neither much addition, nor any improvement, is to be expected. But when scientific principles are disclosed to the artist, he is enabled to draw, from those original sources, an ample store of useful inventions, by which his art is enriched; and thus, the speculative sciences, by their extension to practical purposes, become objects of great public utility.

The arts of colour-making and dyeing were, in very remote ages, carried to the height of perfection, in the countries of Phœnicia, Egypt, Palestine, India, &c. The inhabitants of those countries excelled, also, in the art of imitating gems, and tinging glass and enamel of various colours. The co-

* There is another work of Mr. *Delaval,* written previous to this paper, which is well worth the reader's attention: it is entitled, "An Experimental Inquiry into the Causes and Changles of Colours in Opake and Coloured Bodies."

lours used in very ancient paintings, were as various as those now in use, and greatly superior both in beauty and durability. The paints used by *Apelles* were so bright, that he was obliged to glaze his pictures with a dark coloured varnish, lest the eye should be offended by their brightness: and even these were inferior to what had been used among the ancient Egyptians. Notwithstanding this perfection in dyeing colours, we find the Grecians and Romans continually degrading the useful arts. You may consider this as one of the most striking characters that distinguish the philosophy of the ancients from that of the moderns. The ancients being chiefly engaged in speculations, that might procure them respect, and attract applause, thought the useful arts unworthy their attention: whereas the moderns have cultivated and promoted the useful arts; and we find, the Academy of Sciences of Paris attempting to shed the light of science upon the arts, by publishing a description of them, grounded on the elevated idea, that the industry of a nation cannot fail to be enlightened and increased by a free communication of all the processes it uses; and that the sacrifices it makes, by this publicity, will ever be amply compensated by the advantages it procures.* But why need we go to academies, when we have a fairer and better example in our Lord and Saviour? An example which should teach you to avoid the philosophical pride of the Gentile, and the pharisaical self-sufficiency of the modern infidel. Of our Saviour we read, that having increased in wisdom, he went about doing good. His learning produced not a morose self-complacency, but a lovely affability, and a desire to teach others the glad tidings of joy. The treasures of wisdom were not suffered to rust and canker, locked up from

* *Berthollet*'s Elements of Dyeing.

the public by a supercilious reservedness; but out of them he continually dispersed abroad, and gave to the poor in spirit. The sun, at its rising, found him engaged in this great work; and after it was set, his time was engaged in praying for those whom his days were employed in teaching.

The changes of colour, in permanently coloured bodies, are produced by the same laws which take place in transparent colourless substances; and the experiments, by which they can be investigated, consist of various methods of uniting the colouring particles into larger, or dividing them into smaller masses.

Sir *Isaac Newton* made his experiments chiefly on transparent substances; and in the few places, where he treats of others, acknowledges his deficiency of experiments. He makes the following remark on those bodies, which reflect one kind of light, and transmit another; *viz.* "that if these glasses or liquors were so thick and massy, that no light could get through them, he questions whether they would not, like other opake bodies, appear of one and the same colour, in all positions of the eye, though he could not yet affirm it from experience." It was an opinion of this great philosopher, that all coloured matter reflects the rays of light; some reflecting copiously the more, others the less refrangible rays. He was, likewise, of opinion, that opake bodies reflect the light from their anterior surface, by some power of the body, evenly diffused over, and external to it. With respect to transparent coloured liquors, he says, that a transparent body, which looks of any colour by transmitted light, may also look of the same colour by reflected light; the light of that colour being reflected by the farther surface of that body, or by the air beyond it; and then the reflected colour will be diminished, and perhaps cease, by making the body very thick,

and pitching it on the back part, to diminish the reflexions of its farther surface, so that the light reflected from the tinging particles may predominate. In such case, the reflected light will be apt to vary from that which was transmitted.

To investigate the truth of these opinions, Mr. *Delaval* entered upon a course of experiments with transparent coloured liquors and glasses, as well as with opake and semi-transparent substances. From these he found, that in transparent coloured substances, the colouring matter does not reflect any light; and when, by intercepting the light which was transmitted, it is hindered from passing through such substances, they do not vary from their former colour to any other, but become entirely black.

As this incapacity of the colouring particles of transparent bodies to reflect light, was deduced from very numerous experiments, it may be considered as a general law. It will appear the more extensive, if you consider that, for the most part, the tinging particles of transparent substances are extracted from opake bodies; that the opake bodies owe their colour to these particles, as well as the transparent; and that by the loss of them they are deprived of their colours.

For making his experiments, Mr. *Delaval* used small phials of flint glass, similar to that in my hand; the form is that of a parallelopiped, the height exclusive of the neck is about two inches, the base about an inch square, the neck two inches long. The bottom and three sides of each of these phials was covered with a black varnish; the cylindrical neck, and the anterior side, except at the edges, being left uncovered. He was careful to avoid any crevices in the varnish, that no light might be admitted, except through the neck or anterior side of the phials.

The phials should be perfectly clean, and those liquors that deposit a sediment should not be put into the phials, but at the time when the experiments are to be made. The uncovered side of the phials should not be placed opposite to the window where the light is admitted, because in that situation the light would be reflected from the farthest side of the phial; smooth black substances, reflecting light powerfully, are best situated when the uncovered side forms a right angle with the window.

Taking all these precautions, he viewed a great number of solutions both of coloured metallic salt, and of the tinging matter of vegetables, observing that the colour by reflexion was black, whatever it might be when viewed by transmitted light. If these colours were, however, spread thin upon a white ground, they appear of the same colour as when viewed by transmitted light; but on a black ground they afford no colour, unless the black body be polished, in which case the reflexion of light through it produces the same effect as transmission.

The experiments made with coloured glasses were, in many respects, analogous to those with transparent coloured liquors. For these he made several parcels of coloured glass, composed of borax and white sand. The glass was reduced to powder, and afterwards ground together with the ingredients, by which the colour was to be imparted; a method he found preferable to the usual mode of tinging glasses, as they became little inferior in lustre to real gems.

The result of all his experiments was, that when matter is of such thinness, and the tinge so dilute, that light can be transmitted through it, the glasses then appear vividly coloured; but when they are in large masses, and the tinging matter is more densely diffused through them, they appear black, for these,

as well as the transparent liquors, shew their colour only by transmission.

Having in this manner formed pieces of such glass, two inches thick, he inclosed them in black cloth on all sides, except their anterior and farther surfaces. In this situation each of them shewed a vivid colour when light was transmitted through them, but when the posterior surface was likewise covered with the cloth to prevent the transmission, no other colour but black was exhibited.

From these phenomena he drew the following inferences:

1. *That the colouring particles do not reflect any light.*

2. *That a medium, such as is described by Sir* Isaac Newton, *is diffused over both the anterior and posterior surfaces of the plates, whereby objects are equally and regularly reflected as by a mirror.*

Our author next considers the colouring particles themselves, pure and unmixed with other media. To procure masses made up of such particles, several transparent coloured liquors were reduced to a solid consistence by evaporation; by employing a gentle heat the colouring matter will not be injured, and may have its particles again separated by water or other fluids, and tinging them as before. In this state also the colouring particles reflect no light, and therefore appear uniformly black, whatever be the substance from which they may have been extracted.

He endeavours to prove by experiments on the colouring particle of opake bodies, that these colours are produced on the above-mentioned principles; that they seem black when very dense, but shew their proper tinge when spread thin upon a white ground.

The green of grass, and leaves of plants, being obtained by digesting them in rectified spirit of

wine, and placed in one of the above-mentioned phials, the part in the neck transmitted the vivid green, but that contiguous to the uncovered side of the phial was black.

After the colour had been totally extracted, the leaves remained apparently unaltered as to figure or texture, but were entirely white, or of a white tinged with brown; red, blue, and purple flowers were also digested with spirit of wine, all of which yielded their colouring matter to the spirit, and became white when deprived of it. From most of these flowers the spirit, however, either acquired no tinge at all, or only a very faint one; but when acidulated it became red, and by the addition of an alkali became blue, purple, or green, according to the quantity of the alkali and the nature of the infusion. In these states, all of them, when viewed by transmitted light, or poured upon a white paper, shewed their colours, but universally appeared black by reflexion. Other experiments were tried with other flowers, but the final result was the same, *no colour by reflexion.*

White paper, linen, &c. may be tinged of any of these colours, by dipping them in the infusions; and the consideration of the manner in which the colours are imparted to linen, affords much insight into the manner in which natural colours are produced. It has been already observed, that when the colouring matter of plants is extracted from them, the solid fibrous parts, thus divested of their covering, display their natural whiteness. White linen, paper, &c. are formed of such fibrous vegetable matter, which is bleached by dissolving and detaching the heterogeneous colouring particles: when these, therefore, are dyed or painted with vegetable colours, it is evident that they do not differ in their manner of acting on the rays of light from natural vegetable bodies; both yield their co-

lours by transmitting through the transparent coloured matter the light which is reflected from the white ground.

This white matter ever exists, without any considerable mixture, in plants while they are in a state of vegetation, as cotton, white flowers, the pith, wood, seeds, roots, and other parts of several kinds of vegetables. When decayed leaves of trees have been long exposed to the atmosphere, their coloured juices are sometimes so perfectly extracted that their fibres appear white.

Mr. *Delaval* has rendered ashes intensely white, by carefully calcining them, and afterwards grinding with a small proportion of nitre, and exposing them to such a degree of heat as would cause the nitre to deflagrate with the remaining quantity of phlogiston. Lastly, the ashes were digested with the marine acid, in order to dissolve the ferruginous matter diffused through them, and repeatedly washing the remainder in water.

Hence it would appear, that the earth which forms the substance of plants is white, and separable from that substance which gives to each its peculiar colour; that whenever it is pure and unmixed, or diffused through colourless media, it shews its native whiteness, and is the only vegetable matter endowed with a native whiteness. This white matter may be discovered by other means besides burning; thus roses may be whitened by exposing them to burning sulphur, and the colour may be again restored by the addition of an acid either mineral or vegetable.

Thus it appears, that the colouring matter of the flowers is not discharged or removed, but only dissolved by the phlogiston, and thereby divided into particles too minute to exhibit any colour. In this state, together with the vegetable juice in which they are diffused, they form a colourless transparent

covering, through which the white matter of the flowers is seen untinged. The colouring matter of plants consists, according to Mr. *Delaval*, principally of inflammable matter, and their solubility in, and union with phlogiston.

Colour is destroyed by the rays of the sun. Thus dyed silk and other substances of that kind, when exposed to the sun's light, are deprived of their colour in every part on which the rays are allowed to act; whilst those preserve their colours which are defended from the light. The colours, thus impaired, may be restored, if acids are employed while the injury is recent.

In a word, all Mr. *Delaval*'s experiments shew, that the colouring matter of plants does not exhibit any colour by reflexion, but by transmission only; that their solid earthy substance is a white matter, and that it is this part that has the property of reflexion; that the colours of vegetables are produced by the light reflected from this white, and transmitted from thence through the coloured coat or covering, which is formed on its surface by the colouring particles; that whenever the colouring matter is either discharged or divided by solution into particles too minute to exhibit any colour, the solid earthy substance is exposed to view, and displays that whiteness which is its distinguishing characteristic.

Mr. *Delaval* having settled this point, next proceeded to examine the coloured parts of animal substances, and found them exactly similar, with regard to the manner in which the colour was produced, to the vegetable substances already treated of. The tinctures and infusions of cochineal and kermes yielded their colours when light is transmitted through them, but shew none by reflexion: on diluting fresh ox-gall with water, and examining it in the above-mentioned phials, the part of

it viewed by transmitted light was yellow; but the anterior surface in the lower part of the phial was black, and reflected no colour. Flesh derives its colour entirely from the blood, and when deprived of it the fibres and vessels are perfectly white; as are likewise the membranes, sinews, and bones, when freed from their aqueous and volatile parts. The florid red colour of the flesh arises from the light which is reflected from the white fibrous substance, and transmitted back through the red transparent covering, formed by the blood on every part.

In like manner the red colour of the shells of lobsters after boiling, is no more than a mere superficial covering, spread over the white calcareous earth of which the shells are composed, and may be removed from the surface by scraping or filing. Before the application of heat this superficial covering is much denser, insomuch, that in some parts of the shell it appears quite black, being too thick to admit the passage of the light to the shell and back again; but where this transparent blue colour of the unboiled lobster is thinner, it constantly appears like a blue film. In like manner, the colours of the eggs of certain birds are entirely superficial, and may be scraped off, leaving the white calcareous earth exposed to view.

The case is the same with feathers, which owe their colours entirely to a very thin layer of some transparent matter upon a white ground; this was ascertained by scraping off the superficial colours from certain feathers, which were strong enough to bear the operation, and which separated the coloured layers from the white ground on which they have been naturally spread. The lateral fibres cannot have their colours separated in this manner; but their texture, when viewed by a microscope, seems to indicate, that their colours are produced on them

by no other means than those already related. In a word, he found that in all the animal subjects he examined, the colours were produced by the transmission of light from a white ground through a transparent coloured medium.

The coloured substances of the mineral kingdom are very numerous, and belong principally to two classes, earths and metals; the former, when pure, are all white, and their colour arises from phlogistic or metallic mixtures. Calcareous earths, when indurated, constitute marble, and may be tinged with various colours by means of metallic solutions, all which are similar in their nature to the dyes put upon silk, cotton, or linen, and invariably proceed from the same cause, the transmission of light through a very thin and transparent medium. Flints are formed from siliceous earths, and owe their colour to the state of fire within them; when sufficiently heated, they are rendered white by the loss of the inflammable matter which produced their colour; when impregnated with metals, they form agates, cornelians, jasper, and coloured crystals. The coloured gems also receive their different hues from metal, and may be imitated by glasses tinged with such inflammable or metallic matter as entered into the original substances, all exhibiting their various teints in the same manner, by the transmission of light from a reflected white ground.

Even the colours of metals, according to Mr. *Delaval*, are produced in the same manner. Gold exhibits a white light tinged with yellow; this is grounded on an experiment of Sir *Isaac Newton*, who says, that gold in a white light appears of the same colour as in the day-light, but that on intercepting a due quantity of the yellow-making rays, it will appear white like silver, which shews, that its yellowness arises from an excess of the intercepted rays,

tinging that whiteness with their colour when they are let pass.

A solution of gold is pellucid and colourless; a solution of gold transmits yellow, but reflects no colour. This metal, when united to glass, yields no colour by reflexion, but only by transmission. All these circumstances seem to indicate, that the yellow colour of gold arises from a yellow transparent matter, which is a constituent part of that metal, and that it is equally mixed with the white particles of the gold, and transmits the light reflected by them; in like manner as when silver is gilt, or foils are made by covering white metals with transparent colours. But these factitious coverings are only superficial, whereas the yellow matter of gold is diffused throughout the whole substance of the metal, and appears to envelope and cover each of the white particles; the yellow matter bears to the white about the same proportion that the yellow-making rays, which were intercepted, bear to all the other rays comprized in the white light of the sun.

Sir *Isaac Newton* has shewn, that when the spaces or interstices of bodies are replenished with media of different densities, the bodies are opake; that those superficies of transparent bodies reflect the greatest quantity of light, which intercede media, that differ most in their refractive densities; and that the reflexions of thin transparent substances are considerably stronger than those made by the same substances of a greater thickness. Hence the minute portion of air, or of the rarer medium, which occupies the pores or interstices of dense bodies, is a minute white substance. This is manifest in the whiteness of froth, and of all pellucid colourless substances, such as glass, crystal, or salts reduced to powder, or otherwise flawed; for in all these instances a white light is reflected from the

air or rarer medium, which intercede the particles of the denser substance, whose intertices they occupy.

Hence also we see, why white opake substances are rendered pellucid by being reduced to uniform masses, whose component parts are every where nearly of the same density; for as all pellucid substances are rendered opake and white, by the admixture of pellucid colourless media, of considerably different densities, they are again deprived of their opacity, by extracting these media, which keep their particles at a distance from each other: thus froth or snow, when resolved into water, lose their whiteness, and assume their former pellucid appearance. In like manner the opake white earths are by proper fluxes reduced to pellucid colourless glass; because all reflexions are made at the surfaces of bodies differing in density from the ambient medium, and in the confines of equally dense media there is no reflexion.

As the calces of metal are capable of reflecting their colours by the intervention of air, so, when mixed with oil in making paints, they always assume a darker colour, because the excess of the density of oil over air forms a sensible difference, when comparatively considered with respect to the specific gravity of the rarer metals. From this cause perceptibly less light is reflected from the moleculæ of oil than from those of air, and consequently the mass appears darker. The case is, however, different with such paints as are formed of the denser metals, as vermillion, minium, &c. for though oil differs very considerably from air in its specific density, yet it also differs very much in this respect from the denser metallic powders; and the moleculæ of oil, which divide their particles, act upon the light so strongly, that the reflexion of light occasioned by them cannot be distinguished

from those which are caused by rarer media. Hence, when we mix vermillion or minium with oil, the colour is not sensibly altered.

All the earths, which in their natural state are of a pure white, constitute transparent colourless media when vitrified with proper fluxes, or when dissolved in colourless menstrua; and the saline masses obtainable from their solutions, are transparent and colourless, while they retain the water which is necessary to their chrystallization, and are not flawed or reduced to powder: but after their pores and interstices are opened in such a manner as to admit the air, they become white and opake by the admittance of that rare medium. The earthy particles, which form the solid parts of bodies, generally exceed each other in density; consequently, these particles, when contiguous to the rare media already mentioned, must reflect the rays of light with a force proportionate to their density. The reflective power of bodies does not depend merely upon their excess of density, but upon their difference of density with respect to the surrounding media. Transparent colourless particles, whose density is greatly inferior to that of the media they come between, also powerfully reflect all sorts of rays, and thereby become white; of this kind are the air, or other rare fluids, which occupy the interstices of liquors, and in general of all denser media, where such rare particles are admitted.

Hence we may conclude, that white opake bodies are constituted by the union or contiguity of two or more transparent colourless media, differing considerably from each other in their reflective powers. Of these substances we have examples in frothy emulsions, or other imperfect combinations of pellucid liquors, as milk, snow, calcined or pulverized salts, glass or crystal reduced to powder, white earths, paper, linen, and even those metals which are called

white by mineralogists: for those metals do not appear white, unless their surfaces be rough; as in that case only there are interstices on their surface sufficient to admit the air, and thus make a reflexion of a white and vivid light.

The polished surfaces of metallic mirrors reflect the incident rays equably and regularly according to their several angles of incidence, so that the reflected rays do not interfere with each other, but remain separate and unmixed, and therefore distinctly exhibit their several colours. Hence it is evident, that white surfaces cannot act upon the light as mirrors, because all the rays which are reflected from them are blended in a disorderly and promiscuous manner.

The foregoing phenomena give us some insight into the nature and cause of opacity, as they clearly shew, that even the rarest transparent colourless substances, when their surfaces are adjacent to media differing greatly from them in refractive power, may thereby acquire a perfect opacity, and may assume a hue and resplendence similar to that of white metals; that the rarer pellucid substances cannot by the sight be distinguished from the dense opake metals; and this similarity to the surface of metals not only occurs, when from the roughness of their surfaces they resemble polished metals in whiteness, but also when from their smoothness they resemble the polished surface of metals.

Metals seem to consist entirely of transparent matter, and to derive their apparent opacity and lustre solely from the copious reflexion of light from their surfaces. The analogy between metals and transparent media, as far as concerns their optical properties, will appear to you from the following considerations: 1. All metals dissolved in their proper menstrua are transparent. 2. By the union of two or more transparent media, substances are con-

stituted which are similar to metals in their opacity and lustre, as plumbago and marcasites. 3. The transparent substances of metals, as well as those of minerals, by their union with inflammable matter, acquire the strong reflective powers from which their lustre and opacity arise. 4. The surfaces of pellucid media, such as glass or water, assume a metallic appearance, when by their smoothness, difference of density with respect to the contiguous media, or any other, they are disposed copiously to reflect the light.*

From these considerations it is evident, that opake substances are constituted by the union or contiguity of transparent colourless media, differing from one another in their reflective powers; and that when the common surface, which comes between such media, is plane, equal, and smooth, it reflects the incident rays equally and regularly as a mirror; but when their surface is rough and unequal, or divided into minute particles, it reflects the incident rays irregularly and promiscuously in different directions, and consequently appears white.

When the interstitial vacuities of bodies are so disposed, that the light can preserve its rectilinear course through them, such bodies appear luminous throughout, and are visible in their internal substance; but when their constitution is such as will not allow a free passage to the light, they are then visible only by those rays which are reflected from their surface, and their internal surface is cold and dark.

From various considerations it appears, that the chemical properties of bodies have a considerable influence on their colour; for, doubtless, a force which acts powerfully in refracting the rays, must likewise

* For further particulars, &c. &c. see Mr. *Delaval*'s paper, Memoirs of the Manchester Society, Vol. ii.

influence their reflexion; and it is hardly to be doubted but that the action of fire has a considerable share in the production of colours; indeed its share in the operations of nature is so considerable, that it would be strange if it should be excluded from this more curious part.

By comparing the refractive powers of different bodies, *Newton* found that inflammable substances possess it in a much greater degree than such as are not inflammable. From his observations on this subject, he drew the wonderful conclusion,* that the diamond contained a large quantity of inflammable matter; that water was an intermediate substance between inflammable and uninflammable bodies, and that it supplied vegetables with the inflammable principle; which truths have been seen and demonstrated only in the present day.

Bodies, not transparent in their ordinary state, may be rendered so either by relaxing their parts with heat, so that the light may pass through them more easily, or by giving some new direction, together with an additional force, to the matter of light. Mr. *Hawksbee* was very much surprized to find, that the sealing-wax and the pitch within side a glass globe became so transparent, when the glass was whirled about and rubbed with the hand, that the fingers might be plainly seen on the other side through the coating. Oil is condensed, when cold, into a sort of globules impervious to the light; but when these globules are dissolved, and opened by the action of fire, the oil not only becomes transparent, but appears as bright and shining as if the light were a natural part of its substance.

Many heterogeneous fluids grow dark and muddy with cold, but may soon be clarified again by the application of a moderate heat: red-port wine is

* *Berthollet's* Art of Dyeing, p. 6.

sometimes as foul as if brick-dust were mixed with it, but will soon become bright and clear before the fire.

The quality of transparency is given, by a wise ordination of Providence, to the fluid substance of water, which is so necessary to the life of all animals. Transparency renders glass most valuable; the value of gold is arbitrary, but the worth of glass is intrinsic; its cleanliness and transparency recommend it to our use for the common purposes of life, and render visible the most curious and subtile processes of chemistry and philosophy: in optics, it assists the aged, and gives to man an insight into the wonders of creation.*

LECTURE XXI.

OF PHOSPHORIC BODIES.

The more the nature of light is investigated, the more its relation to fire is discovered; many proofs of this you have already seen, many more will occur in treating of phosphoric bodies. As I have already shewn you, that fire is received and retained in bodies under the form of heat; I have now to shew you, that it is also retained in most substances under the form of light.

By phosphorus, we in general mean those substances which shine in the dark, without emitting heat. Phosphorus is divided into several kinds, known by the names of Bolognian phosphorus, Mr. *Canton*'s phosphorus, *Baldwin*'s phosphorus,

* *Jones*'s Physiological Disquisitions, p. 86.

phosphorus of urine, &c. &c. Besides these, it has been found that the far greater part of terrestrial bodies, upon being exposed to the light, will appear luminous in the dark. This circumstance has occasioned some writers to divide the phosphori into two classes, namely, such as require to be exposed to the light either of the sun or some artificial fire, before they become luminous; and such as do not. Of the first kind are the Bolognian phosphorus, Mr. *Canton*'s phosphorus, the phosphorus from earths, &c. of the latter kind, are rotten wood, the skins of fishes, and the phosphorus of urine. There is another class which becomes luminous by friction or vibration, as sugar, and the solution of phosphorus in spirit of wine.

It has been said, "that philosophy was never under more obligation to what is called chance, than with respect to the discovery of the property of imbibing of light, which was once thought to be peculiar to a certain fossil in the neighbourhood of Bologna, but is now found in many other substances. Not only was a single and leading fact, but a whole series of facts the result of casual observation." You are, I hope, better learned, and will enter your protest against this opinion; for you know that such an opinion, if embraced would deprive you of that satisfaction of mind, which arises from a strong and well-grounded apprehension of a Divine Providence, and of your being constantly under a gracious protection that will guard you from every evil unproductive of greater advantage. It is, indeed, the main basis of prudence and benevolence, as it ensures to you, that whatever you do well shall be attended with success either at present or in futurity, and thus making the good of your fellow-creatures your own highest interest. As this opinion is thus dangerous, it can be no improper digression to consider it more attentively, and the more so, as

you will find another writer, to whom I shall have occasion to refer you on the subject of phosphorus, acknowledging that it was accident which lifted up the veil of nature to him, and attributing to the same blind cause the greatest discoveries that have been made by others.

In common discourse we often, indeed, speak of chance or fortune, as a power influencing the affairs of men, and having a principal share in the direction of all events; as frequently baffling the skill of the wise, the valour of the brave, and the strength of the mighty; as turning the scale of victory, and determining the success of all enterprizes. But if you examine the idea of chance philosophically, you will see that it is neither agent nor power, nor has any other existence except in our own ignorance; for, whatever is ascribed to chance or fortune, we should see performed by other causes, if we had sagacity to discern them.

Chance is no cause of any thing, and serves only to express our ignorance or uncertainty of the manner in which other causes operate; and, in this sense, may be applied to the most cogent necessity or most deliberate design, where we know not the tendency of the one, nor the purpose aimed at by the other.

What is esteemed more casual than weather? Yet nobody doubts of the air being moved, the vapours rarefied, and the clouds condensed, according to a certain impulse received from mechanical causes; but because no mathematician nor naturalist can investigate those causes, so as to calculate what they will produce, we say, the farmer depends upon chance to bring his corn to maturity, and give him a favourable season for his harvest: yet, if we were acquainted with the respective qualities and exact proportions of the causes from whence they proceed, we might calculate the variations of the weather, as well as we now do the changes and eclipses of the

moon. So that an event, happening by chance, does not elude the operations of necessary causes, nor the acts of free agents, nor the provisions of wisdom; for the effects of all three will appear casual when we cannot foresee them. And when it is said, any thing is discovered by chance, or that fortune has had such an influence upon our affairs, no more should be understood by these expressions, than that we are ignorant of the causes acting around us, and affecting the success of our measures. Before accident takes place in those events where our agency has no concern, there must have been natural causes in motion, previous to any thing thus appearing to fall out accidentally among them; and it is only our ignorance of their concurrence and powers that gives chance a title to the production.

Inventions, as we have on a former occasion observed, may appear accidental, and so indeed they are with respect to us, for no man could have seen before-hand the day when they would happen; but accidents arise from certain causes lying in train to produce them; when, and in what manner they shall come to pass, must be referred to the Disposer of all events. It is frequent, in philosophical disquisitions, that the same inquiry produces very different discoveries. The attention paid to the immediate object of investigation does not shut the eye of the observer against any thing else that may offer; and the state into which the subject of examination is put, in order to favour an expected event, often gives origin to another not less interesting.

Nature is nothing more than a conveyancer, whose channels we can in some measure trace, conducting activity from one substance to another; and chance grows like an excrescence from the situation, the circumstances, or mutual concurrence of other causes. We have no experience of any thing that can act otherwise, than by transmitting an operation already

begun. Volitition is the only power we know of that is capable of beginning an action, or giving an impulse it did not first receive. And whoever supposes a substance involuntarily self-moving, or causing a new impulse not in being before, builds upon a mere hypothesis, without any fact within the compass of his observation to support it; whereas, he who holds the contrary, does it because experience of his own actions teaches him that he begins them himself, but that every thing acting involuntarily proceeds in another manner, only carrying on an operation begun by some other agent.

Our views of Providence must be partial and imperfect at best, wherefore much of the wisdom of God will appear foolishness to man; and so does wisdom always appear to such as have not capacity to discern the justness of her measures, nor the ends for which they were pursued: but the more attentively you observe the luminous tracts, you will find them spreading further and further into the dark and exceptionable, and they will open before you an ample field for contemplation. For you will discover wheel within wheel, be able to trace the connection between many of them, discern their exact adjustment to each other, and perceive one adapted to answer various purposes; till at last you will be ready to believe with *Plato*, that the whole world is a tissue of causes and effects, wherein nearly or remotely every thing has an influence upon the rest. From hence we may conclude, not only that the young ravens are fed, and the lilies of the field arrayed in the glory of *Solomon* by the Divine provision; but that, of two sparrows which are sold for a farthing, not one of them falleth to the ground; not a hair is lost of the number upon our heads; not an atom stirs, without the permission of our Heavenly Father.

Thus also God has been pleased, by a long and extraordinary series of events, continuing from the infancy of mankind, to nourish up a religion whereby purer sentiments of himself, and a more extensive charity, may be introduced among the vulgar; and has in his wisdom raised up two trees, Philosophy and Religion, from little seeds, and by slow and successive gradations, whose influence, when mutual, continually tends to purify and meliorate mankind; but, when set at too great a distance from each other, Philosophy becomes a vain babbler, and Religion a superstitious enchantress. When properly mingled, their branches grow more vigorous, extend over a larger compass, and bear fruits of more general use, co-operating in that great design which has been carrying on from the earliest accounts of history by a remarkable course of Providence, calculated for the benefit of the human race in general, distinct from that respecting particular persons; intended to introduce a perfect rectitude of sentiment both in the understanding and inferior faculties of the mind.

Too numerous are the instances to be noticed in these Lectures, and they would lead me too far from the general plan of the work; but one or two I cannot refrain from mentioning. You know how much the art of printing has contributed to the advancement of learning; but this was not the discovery of any philosopher; the world had been long acquainted with the method of stamping inscriptions upon medals and seals, which one would think might naturally have led the ingenious to contrive how to stamp the pages of a book, yet was it never thought of until the appointed time written in the book of heaven.

The magnetic power of the load-stone was known 2000 years ago, but remained an object of idle curiosity for ages, until the use of the needle was dis-

covered; when it opened to us a new world, gave a readier access to the remotest regions of the old, became a means of communicating knowledge, and familiarizing the nations of the earth.

Gunpowder is said to have been discovered by a monk trying experiments, without expectation of any such result; but how greatly has it changed the polity of nations, and civilized the rugged manners of war, making it depend more upon science than bodily strength or personal courage, and uniting the civil with the military interest! And in remote consequence of these inventions concurring with other incidents in the amazing series, mankind is become better united and civilized; every nation has some intercourse with others, and the more barbarous gradually take a tincture from the more humane.

Let us now return to our phosphoric bodies, and first to the Bolognian phosphorus. This was discovered about the year 1630, by *Vincenzo Cascariolo*, a shoe-maker of Bologna; who, being in quest of some chemical secret, among other things, tried a calcination of some stones found in the neighbourhood of that city; and observed, that whenever this stone was taken into the dark, after having been exposed to the light, it was plainly visible by a light issuing from itself, continuing to appear for some time, when it became invisible; but upon returning it to the light, and then carrying it back to its former situation, it exhibited the same appearance as before.

Of bodies that give light in the dark there are several kinds; for, some bodies throw out light spontaneously, and others upon being excited. Of the former kind, some shine with a natural light, as glow-worms, dates, and a variety of aquatics; others possess an adventitious light, as rotten wood, and the flesh of some quadrupeds and birds. These last

are not naturally phosphoric, but owe that property to some particular cause, which generally is putrefaction, and sometimes an insensible change in the natural constitution of the parts.

Those bodies which become phosphori upon being excited, or whose phosphoric property is at least assisted by excitation, may be distributed into different species according to the mode in which this property is brought into action. These modes are, attrition, agitation, heat, the free admission of air, and being exposed to the external light.

Bodies of every kind become phosphori by attrition, provided they can bear that force of friction which is sufficient to produce the reluctant light that is hid in their substances; agitation agrees mostly with liquid substances, as sea-water.

The emerald phosphorus, and many gems, and amongst these, not a few diamonds, the lapis lazuli, and a great part of the mountain crystals, become phosphoric by the application of heat.

The free admission of air not only produces light in using the phosphorus of Konkel, but even a blaze of fire, where friction is used. The phosphorus of Homberg burns also furiously upon the approach of air.

The last class, those which act after being exposed to the external light, are exceeding numerous; there seem but two substances which do not emit light when tried in this way, *viz.* water in its fluid state, and metals. All bodies then whatever, except water and metals, have a power of imbibing light, and, when placed in proper circumstances, of emitting it again.

This has been fully proved by the experiments of Mr. *Beccaria*,* of Bologna, and Mr. *Wilson*, which have been made in the most satisfactory manner;

* Not *Beccaria* the electrician.

indeed, so great has been their diligence, that there are but little hopes of adding any thing considerable to what they have done.

A very weak light can be visible only in great darkness. When the sun is in its meridian splendor, the moon and stars are totally obscured; and yet when his superior light is withdrawn, how plainly the moon and stars appear. Art will produce a degree of darkness far exceeding that of the night, and in such darkness the weakest light will become visible. Mr. *Wilson*, therefore, to judge of the illumination of bodies when brought from the light, made his experiments in a closet about six feet by five and an half, the height about nine feet. It was painted black, or covered with black baize in every part, and had two doors which were five or six inches broader and longer than the space to enter at. There are two curtains of black cloth over the hole where the hand was occasionally put out, to expose bodies to the light; the outer one and inner one each consisted of three doubles: all these were considerably larger than the hole, which was about fifteen inches diameter, and opened to the south. There were small leaden weights fastened to the bottom of each curtain, to preserve them in their places when the hand was drawn into the room; two curved pipes were fitted to the closet, one communicating with the external air from the top of the room, the other from the bottom, for the sake of breathing freely; by means of this closet any substances could be easily exposed to the light, or withdrawn from it.

Numerous, and well worthy of your attention, are the experiments made by Mr. *Wilson* in this closet; here almost every substance was found to be phosphoric; but calcined oyster-shells and white paper possessed this power in an eminent degree. A piece of paper with a key being exposed to the light, and

again taken into the room, the key was then removed, and there remained as much of the paper dark as had been covered by the key, leaving a black space exactly of the same figure as the key. A gentleman's hand, and part of a ruffle, being dipped in the light, and then suddenly withdrawn, appeared luminous; and as every other part of the body was dark, it looked like a hand with a bit of ruffle suspended in the air, so that the human body was found, like others, to be phosphoric.

Though fluid water is incapable of emitting light, yet when condensed into the form of ice or snow, it assumes it, like other species of matter. This accounts for the light afforded by snow lying on the ground, even when the heavens are involved in utter darkness; being exposed to the light all day, it absorbs a great deal of light, and is thereby enabled to give out a considerable quantity in the night.

It is probable, that all the bodies with which we are surrounded are sufficiently endued with this phosphoretic property, to enable animals to find their food in the night. To this it may be added, that the eyes of animals are better constructed for collecting light than the human eye: thus the substance spread out behind the retina of cats, owls, &c. is white, which reflects the most light; that behind the retina of graminivorous animals is green; lastly, that in the human eye is black; hence we require more light than animals to dicover objects, but our vision is more perfect.

From the foregoing experiments it appears, that the world is stocked with a variety of occasional phosphori, from which light is insensibly evaporating where we should never have looked for it, nor could possibly have detected it, but for the subtile mode of examination contrived by *Beccaria* and *Wilson*.

OF CANTON'S PHOSPHORUS.

To prepare this, take some oyster-shells, and calcine them, by keeping them in a good coal fire for half an hour; let the purest part of the calx be pulverized and sifted; to three parts of this powder add one of the flowers of sulphur, and mix them well together; put the mixture into a crucible, and ram it tightly therein; then let it be placed in the middle of a fire, where it must be kept red-hot for an hour at least, and then set to cool. When it is cold, turn it out of the crucible, and, cutting or breaking it to pieces, scrape off upon trial the brightest parts, which, if good, will form a white powder, which you may preserve by keeping it in a phial, with a ground stopple.

The quantity of light which a little of this phosphorus gives when first brought into a dark room, after it has been exposed for a few seconds to the light of the day, is sufficient to shew the hour by a watch, if the eyes have been previously shut for one or two minutes.

By this phosphorus you may represent celestial objects, such as Saturn and his ring, the phases of the moon, &c. If the figures of them made of wood, be wetted with the white of an egg, and then covered over with the phosphorus, a flash from the discharge of an electrical jar will illuminate the phosphorus as well as the light of the day.

By a variety of experiments made with this phosphorus it appears, that when it had emitted all the light it could in the common state of the atmosphere, it would emit more on the application of heat, but that the same degree of heat would render it luminous for a certain time.

Let one end of a bar of iron of about an inch square, or a poker, be made red-hot, and laid hori-

zontally in a darkened room, till, by cooling, it ceases to shine, or is barely visible; then bring a little dry phosphorus, which has been exposed to the light, in a glass ball hermetically sealed as near the hot iron as possible; and the phosphorus, though invisible before, will in a few seconds begin to shine, and will discharge its light so very fast, as to be entirely exhausted thereof in less than a minute, and will shine no more by the same treatment till it has been again exposed to the light. By this heat, light received from a candle, or even from the moon, may be seen several days after; and phosphorus, that will afford no more light by the heat of boiling water, will shine again by the heat of hot iron. By means of this heat, phosphorus, which had been kept in darkness more than six months, was found to give a considerable degree of light.

Mr. *Wilson*, in his treatise on phosphori, has made a variety of experiments on oyster-shells calcined, and combined with nitrous acid, and without it; in all cases they acquired the phosphoric quality in a very high degree. He poured some aqua fortis, previously impregnated with copper, on a quantity of calcined oyster-shells, so as to form them into a kind of paste; this paste was put into a crucible in a pretty hot fire, for about forty minutes. Having taken out the mass, and waited till it was cool, he presented it to the external light; on bringing it back suddenly to the dark, he was surprized with the appearance of a variety of colours like those of the rainbow, but much more vivid. In consequence of this appearance of the prismatic colours, he repeated the experiment in various ways; combining the calcined oyster-shells with different metals, and metallic solutions; with the different acids, alkaline, and neutral salts; as well as with sulphur, charcoal, and other inflammable

substances; and by all of these he produced phosphori which emitted variously-coloured light.

What is more remarkable, he found that oyster-shells possessed the phosphoretic quality, and would exhibit the prismatic colours in a surprizing degree; and for this purpose nothing more was necessary than to put them in a good sea-coal fire, and keep them there for some time. On scaling off the internal yellowish surface of each shell, they become excellent phosphori, and exhibit the most beautiful and vivid colours.

From Mr. *Wilson*'s experiments it appears, that fire or inflammable matter is essentially necessary towards producing prismatic colours in phosphoric substances; that there is no particular disposition in the shell to exhibit any particular colour without the aid and assistance of the inflammable principle; and that the several parts of the shells exhibit such colours as correspond with the different quantities of inflammable matter that they respectively contain.

The inflammable principle appears to be so weakly combined, that it is easily disengaged in consequence of the action of light.

Mr. *Beccaria* has attempted to shew, that phosphorus emitted the very same light that it received, and no other; and Dr. *Priestley* concluded from hence, that *Zanotti* was wrong in asserting, that phosphori shine by their own native light, after they have been kindled by foreign light. *Zanotti* appears, from Mr. *Wilson*'s experiments, to have been considerably nearer the truth than Dr. *Priestley* apprehends; as he seems fully to have disproved, by his numerous and accurate experiments, the opinion of *Beccaria*.

The experiments on phosphori may, perhaps, be accounted for by considering, that as an heated iron,

which is dark by day-light, appears red and fiery when carried into a dark room, having acquired but a part of that ignition which renders it luminous in the open day-light; so other bodies are capable of an incipient ignition, which is perceptible to the eye in artificial darkness; and it is this incipient ignition which brings them under the denomination of phosphori. It is remarkable, that a degree of light is discernible in heated oil, when viewed in such a dark medium; and that even cold water does not immediately extinguish the light imbibed by sugar, gum, paper, &c.

It has long been observed, that bodies, when beginning to putrefy, emit light: this has been observed in meat, fish, and particularly in wood; in meat the softest parts are most luminous, it looks, when in this state, as if sprinkled over with gems, and upon touching it the luminous particles come off on your fingers: this, however, does not take place before a certain degree of putrefaction is induced, and ceases after it has proceeded to a further degree.

The luminous appearance of the sea has long been known, and variously accounted for; it now seems to be generally attributed to a phosphoretic appearance, arising from putrefied materials from fish and vegetables, which rise to the surface of the water in the form of scum, and when agitated yield more light than when at rest.

There is a remarkable difference between the light of rotten wood and fishes, and that of phosphorus of urine, even when it is not in an ignited state; for this last does not cease to be luminous even when included within an exhausted receiver; the contrary of which happens to rotten wood and fishes. When kept in water and placed in warm air, the phosphorus of urine discharges such large

and bright flashes into the air above it, as are apt to surprize, and even to frighten those who are unacquainted with it.

Phosphori, in the most extensive meaning of the word, may be considered as bodies giving light; though more properly they are those bodies which give a faint light, visible only in the dark, upon being rubbed, or after having been exposed to the influence of light.*

Bodies shine in the dark in consequence of an excess in their heat, and by the emission of this light the heat is in some degree dissipated; the substance of the body is thus changed in its temperature, or in relation to heat.

Bodies emit light also in consequence of the resolution of phlogistic matter, which had been contained in their substance or composition.

But bodies also emit light without being sensibly affected in their temperature, or having the composition of their substance changed; this change may be effected by that active principle, which there are many reasons for supposing to reside on the surfaces of bodies.

Particular species of bodies which have a peculiar power in their substance, by which incident light is reflected, or which have a power of absorbing light, do not become phosphoretic by having the powers of their surfaces excited by friction or incident light; but those bodies which do not thus eminently absorb or reflect light, and do not conduct electricity by their substance, are all in some degree phosphoretic.

That the light emitted from the phosphoretic body is not the identical light to which the body has been exposed, is proved by Mr. *Wilson*'s experiments.

* *Hutton*'s Dissertations on different Subjects of Natural Philosophy.

It would therefore appear, that the species of the emitted light arises only from the particular disposition of the phosphoretic body, and that by being thus properly disposed, the same phosphoretic bodies, may, after being excited, emit any one particular species of coloured light, according to the manner in which it had been disposed for this operation of producing light.

From the experiments of Mr. *Wilson* it appears, that it is not the exciting light which is emitted by the body shining in the dark; it is not the emitted light, or light of the same species, which has the greatest power of exciting the phosphorus to shine; but the light which has so great an energy in exciting the phosphorus, is that species of light which is placed at the other extremity of the prismatic order, or most opposite in the rule of its refrangibility from that of the emitted light.

Thus, though the incident light be the cause of shining by exciting this quality in the phosphoretic body, yet there is interposed another operation between the incidence and the emission of light; and there is reason to suppose, that the particular species of light emitted from the phosphoretic surface, depends on the electric fluid put into action by the incident light.

Phosphoretic and phlogistic bodies agree in containing a quantity of light, which is not in any perceived state of heat.

Although phlogistic and phosphoretic bodies emit light upon the same principles, so far as this depends upon luminous matter contained in the bodies, which is set at liberty during the operation, by which it is rendered luminous; yet the manner in which the luminous matter is set at liberty, is very different, as is that also by which the luminous matter is retained. The exposure to the atmosphere is essential to the emission of light from

phlogistic bodies; but this is a circumstance indifferent or unnecessary for the same operation in those that are phosphoretic. In phosphoretic bodies there is no difference perceived after they have lost their shining qualities; but this is not the case with phlogistic bodies, where the greatest difference is perceived on the abstraction of their luminous matter.

Phosphoretic bodies furnish us with a strong additional proof of a principle already noticed, that light is matter which may continue for some time therein without exciting heat, and may be again separated therefrom, and resume its character of light, as will appear by considering,

1st. That a phosporetic body is made luminous only by its having been exposed to light. 2dly. That it must be exposed to light of a certain intensity. 3dly. That provided the light falling upon the phosphoretic body be sufficiently intense, the most instantaneous exposition suffices to saturate the body, so as to make it emit light visible in the dark, equally as if it had been exposed thereto for a longer time.

It follows from hence, that light is matter, and that this solar substance may be retained in connexion with a body, either upon its surface, or connected with the gravitating matter of which the body consists.

GENERAL OBSERVATIONS CONCERNING SEVERAL OPERATIONS OF LIGHT IN RELATION TO BODIES. EXTRACTED FROM DR. HUTTON'S DISSERTATIONS ON DIFFERENT SUBJECTS OF NATURAL PHILOSOPHY.

A body heated to an intense degree gives light, and light may be considered as matter moving in a straight course directed from a body. It is a matter

of general observation, confirmed by the experiments of Mr. *Pictet*, that the intensity of heat in a body is diminished in proportion to the light which is emitted from the body.

Light emitted from a hot body, and meeting in its course with a colder body, whose temperature may be accurately measured, may be either reflected from the surface of the opposing body, or extinguished within the substance of the body. In this last case, if, in proportion to the light extinguished in the body, the intensity of heat be increased, it may be concluded, that fire is moved from the body in light, but the intensity of heat in a body is increased in proportion as light therein is extinguished; it therefore is, as to matter, the same with fire.

Heat and light may thus be considered as different modifications of the same matter, or different actions, according to the several conditions in which that matter may be placed.

Light, which is incident in relation to a body, may be either reflected or transmitted, or both, and that in the greatest part. So far as light is reflected from the surface, or transmitted through the substance of a body, no heat should be excited in consequence of this modification of matter, which is not that of heat. This is consistent with observation, for no heat is excited by reflected or transmitted light.

By fire the volume of bodies may be changed; by light the figure of bodies may be perceived; but we know not whether fire and light have a proper bodily form; yet their existence is manifested by their effects; their actions, or laws of motion, are inferred or discerned by reason.

Nothing is more distinct than light and fire in their proper sensible qualities, but these sensible qualities are conditional. On the one hand, fire

is not felt, if the sensitive body preserves its natural or proper quantity of this substance; on the other hand, light is not perceived when falling on the skin or hands. As the conditions therefore necessary to the productions of those several sensations are perfectly different, from those different sensations we cannot conclude the matter employed in both is not the same.

Bodies in relation to light are either luminous or illuminated. It is only by means of light that bodies become visible, and this light must proceed from luminous bodies.

As bodies, by having the intensity of their heat sufficiently increased, may become luminous or made to emit light; if the light of bodies is considered in this most general view, the class of luminous bodies will be thereby greatly augmented.

In order to distinguish bodies that are properly luminous from those that only emit light in consequence of heat, it will be proper to observe, that bodies emitting light in this last manner, are not changed further than necessarily follows from the operation by which the proper degree of heat is produced; consequently, these bodies may return to their former state, and, by being again heated, may have these operations repeated without limitation. But bodies properly luminous are limited in the quantity of light which they had retained, and which they are able to emit; after which those bodies, exhausted of their proper light, can only be luminous, in consequence of fire acting as heat.

Bodies that are eminently luminous must emit a quantity of light which had been contained in them; such bodies must therefore contain a certain species of matter in their substance, and this is called phlogistic inflammable or combustible matter. Now this phlogiston may, in the chemical operations of matter, be translated from the substance of one body

to another; by which means bodies are made phlogistic, or capable of becoming eminently luminous, that were not so before.

All bodies that are made to give light require a certain degree of heat, without which they will remain without giving light; so that all bodies that are to emit light, whether properly luminous or not, agree in having the emission of light as a consequence of heat, and in requiring a certain intensity of heat as a necessary condition for the emission of light: so far as this is the case, without heat bodies could not give light.

Heated bodies emitting light, I have already observed, are thereby continually losing heat, while colder bodies exposed to light, are receiving heat; such bodies, therefore, must have both their heat and light continually diminished, by forming an equilibrium of heat with contiguous and surrounding bodies.

It is otherwise with combustible bodies, for though these require a certain degree of heat as a condition of their emitting light; yet, as they also emit light upon other principles, so, during their emission of light, appearances take place very different from those of bodies that are only luminous by the intensity of their heat.

The solar substance appears to be variously modified in relation to bodies, or differently disposed with regard to space and things; it is in one place fire, in another light, in a third electricity. In each of these modifications there are properly perceived actions with different intentions, but not opposite natures. From various similitudes, the several actions are concluded as belonging to the same kind of matter, from the separate purposes perceived in their various distinguished or different modifications.

Bodies, in relation to light, may be distinguished as of two different kinds; one kind giving light of their own, or which had been part of their substance, immediately before the act of emission; the other kind giving no light, except that with which they are illuminated from other bodies. Hence a general distinction of bodies, some being luminous, others dark or opake.

Bodies, in relation to that light with which they are illuminated, are considered as of two kinds, either transparent or opake. Here is therefore another sense, in which opacity may be taken; consequently, before the various affections of light and bodies are examined, it will be proper to have a distinct notion of this quality, which may perhaps be considered in different senses.

Opacity, as a quality in bodies, may be considered either in a more limited or in a more extensive sense; in the one case it signifies want of transparency; in the other, that no light comes from a body. The first is a quality, properly or only opposed to transparency; the last will signify darkness in a body, from whatever cause.

Opacity being considered in the most extensive sense, then, as there are two different principles of lumination, or modes by which light may proceed from a body, the quality of opacity may be examined in relation to each.

Light properly belonging to a body, being emitted, is said to come from a luminous body; therefore opacity, in being applied to a body, may mean a body that emits no light of its own. But as, in this case, the light to be emitted is supposed to be part of the body, or its substance's opacity, in this particular sense, will mean a quality only in relation to the substance of the body, and not to its form, that is, to its figure and volume.

At the same time that this quality of opacity is thus found to be applicable only to the substance of a body, it must also appear that this is only a negative quality, meaning, that the body has no light of its own to emit; or, if it does contain luminous matter, that there are not proper conditions for the emission of that substance.

With regard to the other mode of giving light, when a body may have opacity, or shall be considered as opake, this relates to incident or foreign light. Light falling on a body may be either reflected, in which case it illuminates the body, or it may be transmitted, in which case the body is transparent; in neither of those two cases, is opacity, as a quality, necessarily perceived in that body. But light entering the surface of the body, and being there retained without immediate emission, here is to be perceived a quality in the body, which, at the same time that it is a positive quality, is also, properly speaking, the quality of opacity, as being opposed to the transmission of light, which is transparency.

In this case of opacity, considered as a positive quality, no relation is to be perceived between form, figure, or volume, the proper qualities of a body, and this quality or power in relation to light; therefore opacity, in this most proper sense, must be considered as a quality, which, whilst it is positive, belongs only to the substance of the body, and may be properly examined without attending to the form or volume.

Transparency consisting in the free transmission of light through a body, the absolute solidity of the particles of matter in a body must be inconsistent with that quality; for, as transparent bodies transmit light equally in all directions, it is only by supposing the resisting parts of the body to be the un-

resisting parts, in a ratio less than any assignable proportion, that this quality of perfect transparency can be thought consistent with the extension, and direct motion of the rays of light. At the same time, in judging from the hardness and incompressibility, if these are supposed to depend upon the solidity of the substance, there must be a great proportion of matter in the body.

But as there is no reason to doubt of the perfect transparency of bodies, considered solely as a transmitting quality, there is perhaps every reason that can be drawn from the concurring testimony of natural appearances, to justify the supposition, that, in a transparent body, the absolute volume of matter necessarily opposing the passage of light, and the absolute volume of the parts of light that must necessarily be opposed in passing through that body, are, to the rest of the space, in a ratio less than any assignable proportion. This being the case, it must be evident, that those two qualities of transparency in relation to the rays of light, and resisting power in relation to external force, are things plainly inconsistent, if we are to suppose solid matter to be the principal of bodies.

On the other hand, opacity, considered as a quality by which transmission through the substance of a body is refused, will appear not to arise from the necessary resistance of the matter in a body to the rays of light from its extension, nor from the mechanical disposition of that matter in any conceivable manner; for, 1st. According to any way of forming a judgment, with regard to the quantity of matter in a body, that quantity does not appear to have any influence in producing opacity.

2dly. The smallest examinable quantity of matter, sufficiently opake, appears to be as effectual to interrupt the passage of light, as the greatest quantity of matter not sufficiently opake; at the same time

this quality of opacity in a body, does not appear to be altered by any mechanical change or disposition of the parts: therefore, though the transparency of bodies were explicable from the supposition of infinite strength and infinite rarity, in the solid matter and construction of bodies, this theory or supposition would still be inconsistent with the opposite quality, that is, opacity in bodies; for, while the greatest quantity of a dense transparent substance transmits light perfectly in every possible direction, the smallest quantity of a rare opake substance suffices to arrest light or retain it, without reflexion or transmission. It is thus impossible, upon mechanical principles, to reconcile those two different qualities of bodies; therefore, independent of the insurmountable difficulty of constructing the solid matter of bodies for those two opposite purposes, here is a demonstration from the simple quantities of the matter in bodies, by which it is proved, that opacity does not arise from any mechanical construction of solid matter; and, therefore, that bodies are not composed of solid matter and space, separate and contiguous.

Light appears to pass through the substance of an homogeneous transparent body with equal facility, as it is conceived to move in the rarest or voidest space; consequently, the matter of such a body makes no sensible resistance to light. Therefore, it may be inquired, what kind of matter is this, that has not the power of resisting light? Or, what particular powers in bodies are associated with this deficiency of power in relation to light?

The hardest and softest bodies are equally transparent; light does not appear to be transmitted through a diamond with less facility than through the air: therefore, that power in bodies, which resists the motion of the parts in relation to each other with so great intensity, does not resist the

motion of light, or this particular modification of matter.

Fluid and concreted bodies, water and crystal, are equally transparent; consequently, that power by which the parts of bodies are directed to particular situations, does not interpose any resistance to the passage of light.

Heavy bodies may be transparent as well as lighter bodies; glass of lead, crystal, ice, air, are all transparent bodies; therefore, as the matter of light appears to have no gravitating power, the power of gravitation in bodies makes no opposition or resistance to the motion of light.

The particular attractive powers of substances appear to be no more disposed to resist the matter of light, than the general powers of bodies which have been considered; thus air, water, acid, alkali, and neutrals, are all transparent.

Therefore, from the examination of bodies with regard to transparency, this general conclusion may be formed, that the attractive gravitating matter in bodies appears to have no power calculated to oppose and resist light.

But in opake bodies, there are powers by which light is effectually resisted.

In the transparent bodies already examined, every species of substance has been considered, except one; and this, which is phlogistic substance, not yet examined with regard to light, has been found capable of opposing, resisting, and changing every general attractive or gravitating power in bodies: therefore, on finding this substance properly adapted, whether in a mediate or immediate manner, for the opposition, resistance, and change of light, the qualities of transparency and opacity in bodies will be properly explained; at the same time that this natural appearance of transparent and opake bodies, being in perfect consistency with the theory of

matter already investigated, will add that confirmation which in physical subjects is required.

Transparent bodies have been considered as not affecting the light, which thus traverses their substance with perfect facility; but it is a necessary condition for this purpose, that the substance be homogeneous, and equal in its density, or, that the body be sufficiently uniform in relation to the volume occupied by its several parts; for a greater degree of density in one part of a body, otherwise perfectly homogeneous, disposes the body to affect the light in that part where the change of density takes place.

Hence the surfaces of contiguous bodies, which are transparent, but of different densities, are observed to affect light in different ways, and according to a certain rule.

Thus reflexion, refraction, and extinction, are affections of light by transparent bodies, the rule or laws of which, to the honour of philosophy, have been so well investigated.

From the particular laws observed in those cases, there is reason to conclude, that there are certain powers situated in a place, corresponding to the surfaces of bodies, by which light, that otherwise would be unaffected, may be both deflected in its course, and arrested in its motion. But on considering electricity, there are found certain powers situated precisely in this place; and, as the matter of electricity, which is properly situated in this place, and that proper to phlogistic substance by which alone light has appeared to be affected, are of the same kind, being different modifications of the same species of matter, there is reason to conclude, that the powers by which light is affected at the sufaces of transparent bodies, are of the same nature with those by which, in opake bodies, light is also found to be affected.

OF THE INFLEXIONS OF THE RAYS OF LIGHT WHICH PASS IN THE VICINITIES OF BODIES.

The experiments on this subject by Sir *Isaac Newton* were the last that he made, and are acknowledged by himself to be incomplete; those who have followed him in this delicate and important department of natural philosophy, have done little more than added some insulated facts to those observed by him. The law followed by the powers that inflect the light, and the limits of its action, are yet unknown. One, however, of the general results from the experiments is, *that bodies act upon light at small distances by attraction and repulsion.*

If a beam of the sun's light be admitted into a darkened chamber, through a hole of the breadth of a forty-secondth part of an inch, or thereabouts, the shadows of hair, threads, pins, straws, &c. appear considerably larger than they would be if the light passed by them in straight lines. For example, a hair, whose breadth was the 280th part of an inch, being held in this light, at about twelve feet from the hole, cast a shadow, which at the distance of four inches from the hair was the 60th part of an inch broad, that is, above four times the breadth of the hair. And the effect is the same, though the density of the medium contiguous to the small body be altered, the shadow at like distances being equal, whether it was in the open air, or inclosed between two plates of wet glass, care being taken that the incidence and emergence of the ray was perpendicular to the glasses. The scratches on the surface, or veins in the glass, cast shadows broader than they ought to be, from the usual refraction which might arise from any action of the ambient medium.

Let x, *plate* 7, *fig.* 2, be a hair placed in the beam; A D G, B E H, K N Q, L O R, rays of light passing by the sides of it, are bent at x, and falling upon the paper G Q, the two rays T I, V S, pass by the hair without being deflected; but all the rays between T I and V S are bent in passing by the hair, and turned aside from the shadow I S. The light passing nearest the hair, as at D and N, is most bent passing to G and Q; those that are farther off, as at E and O, are less bent; and so on to T I and V S: consequently, the action upon the rays of light is strongest at the least distances, and grows weaker and weaker as the distance of the ray passing by is increased.

The shadows of all bodies in this light are bordered with three parallel fringes of coloured light; the nearest to the shadow is the brightest, and the furthest very faint; the order of the colours, reckoning from the innermost, are violet, blue, green, yellow, red. On looking at the sun through a feather or black ribbon, held close to the eye, several fringes of colours will appear.

Let a beam of the sun's light be admitted through a hole one-fourth of an inch broad; place a sheet of pasteboard, blacked on both sides, at about three feet from the hole; in the middle of the pasteboard let there be a hole, three-fourths of an inch square, for the light to pass through; behind the pasteboard fasten the blade of a sharp knife, so as to stop part of the light going through the hole. The knife and pasteboard are to be parallel, and both to be at right angles to the beam. Let a part of the light, which passes by the knife's edge, fall upon a white paper at about three feet distance, and there will be two streams of light shooting out both ways into the shadow, somewhat like the tails of comets. These streams being very faint, it is necessary, in order to

see them distinctly, to let the direct rays pass through a hole in the paper on a piece of black cloth; the light of the streams is then perceptible on the paper to the distance of six or eight inches from the sun's direct light each way, and in all the progress from that direct light decreases gradually till it becomes insensible.

Placing another knife with its edge very near and parallel to the first, if they be distant the 400th part of an inch, the stream of light passing between them will be divided, parting in the middle, and leaving a dark shadow in the interval: as the edges approach, the shadow grows broader, and the stream narrower at the inner end: so that the light that is least bent goes to the inner end of the stream, and passes at the greatest distance from the edges. This distance is about the 800th part of an inch; when the shadow begins first, the light which passes at less distances is more bent, and goes to that side which is farthest from the direct light: a little before the shadows appear, the fringes commence on both sides, and as the knives approach, they grow more distinct and larger; till, upon contact of the knives, the whole light vanishes, leaving its place to the shadow.

Admit a beam of the sun's light through a small hole, made by a pin in a thin plate of lead, and place a prism at the hole to refract the light on the opposite wall. The shadows of all bodies held in the coloured light, are bordered with fringes of the colour of that light in which they are held; in the red, they are red; in the blue, blue, &c. but the fringes in the red light are the largest; those in the violet, least; the green between both, and this at all distances from the small hole.

So that the rays which made the fringes in the red light, passed by the hair at a greater distance than those which made the violet fringes; consequently, the hair in causing these fringes, acted similarly

upon the red rays, which were at a greater distance, as upon the violet at less distances; and by these actions disposed the red light into larger fringes, and violet into smaller, &c. without changing the colour of the rays.

When a hair is held in a white beam of solar light, and casts a shadow which is bordered by three fringes of coloured light, these colours arise from the various inflections by which the rays are separated, and, being separated, produce each its own colour. In the last experiment, where the rays are separated before the light comes to the hair, the red or least refrangible rays were inflected at greater distances, and the violet or most refrangible rays at a less distance; making three violet fringes at a less distance, whilst the red makes three red fringes at a greater distance; the mean rays making three fringes of their proper colours at mean distances from the shadow of the hair. In the white light these various colours are separated by the various inflection of the rays, and their fringes appear altogether; the innermost being contiguous, make one broad fringe, composed of all the colours in due order, the violet being next the shadow and the red farthest off, and the rest in their places. In like manner the middlemost fringes constitute one broad fringe of all their colours, and the outmost fringes compose another broad fringe like the rest; and these are the three fringes of coloured light with which the shadows of all bodies are bordered.

From these, and some other experiments of the same tendency, it may be inferred that the rays of light are influenced by some power that turns them out of their direct road; and as this power bends the rays, not into the shadow of the bodies from whence the influence is supposed to proceed, but from the shadow, it has been considered as a repulsive power which is strongest at the least distance.

OF THE ACTION OF LIGHT ON BODIES, AND THAT THE COLOUR OF PLANTS, &c. DEPENDS ON LIGHT.

You will often find that philosophical knowledge makes quicker advances by reasoning upon known facts, than by discovering new ones, which, though they enlarge and add to the subjects we ought to reason upon, are apt by their novelty to surprize us into hasty undigested theories. We have a strange propensity to be looking either behind or before us for variety, instead of cultivating the fruitful spot we stand upon. I am led to make this and some of the following observations from the subject before us, which has been too much neglected by modern philosophers: we have treatises on light, as separated and divided by the prism; on heat, as measured by the thermometer; but none on that ocean of the solar fluid, in which all bodies are as it were immersed;* none upon the various influences of the sun, upon which the life and activity of all things in this natural world depend. They seem to have forgotten, that the processes continually carrying on in nature, on every side, are as much the instruments of knowledge, as the more refined apparatus of the experimental philosopher. Sense and experience acquaint us with the course and analogy of appearances or natural effects; though reason and intellect introduce us into the knowledge of their causes.

To avoid the conjectural method of some former philosophers, those of the present day are continually labouring to accumulate unconnected facts; thinking every new form, or every new appearance, an important discovery; seldom endeavouring to trace out their connection with superior and inferior

* *Young*'s Essay on the Power and Mechanism of Nature.

causes, on which all their real powers and activities depend. If we stop at experiments, without proceeding any further, we shall never arrive at any causes; and if we rely wholly upon experiment, we shall come at none but false ones; because the principal agent in nature is so subtile as to elude both sense and experiment, so that they can never discover it; though, when we have been told of it, they will serve to demonstrate its observations.

The ancients paid little attention to experimental philosophy, but devoted themselves with a truly philosophical ardour to the observations of the phenomena of nature; and that process was consonant to sound reason, for experiment is only properly called in to fill up the chasm which simple observation necessarily leaves.

The department of experimental philosophy is the unfolding of those phenomena, whose causes cannot be discovered by unassisted reason, and whose connection it cannot trace; the advancement therefore of this branch of science depends on the number and accuracy of our observations, with respect to the relations which natural objects have to each other.

It has been well observed by Dr. *G. Fordyce*,* that "all our knowledge of every thing whatever must arise from experiment only, that is, from the evidence our senses give us of what appearances nature, in other words, the creatures of the Almighty, give impressions of." Yet, "some of these impressions are received from the ideas that arise from things not at all under our dominion, or from circumstances more immediately governed by the Almighty. Thus, for example, a man sees a tree lose its leaves in autumn, sees them renewed in spring, and a new growth takes place during the summer; he sees the blossoms open it the spring; these he finds followed

* *Fordyce* on the Digestion of Food.

by the fruit, which, if it falls into the earth, is capable of producing new trees of the same species; or he sees it gathered by animals, and affording nourishment. In this mode of acquiring knowledge, man is totally passive; he did not contrive to make leaves fall in the autumn, and be re-produced in spring; he did not contrive to make new wood grow in the summer, nor that blossoms should open, that the seeds should be impregnated with the embryo; he did not contrive that the fruit should grow, nor did he teach animals that it was fit for their nourishment. What knowledge is acquired by attention to these natural circumstances, has been called observation. It is, indeed, a contemplation of the benevolence of the Almighty, giving nourishment and happiness to all the inhabitants of the earth.

"The minds of mankind, not satisfied with their powers of observation of what passes in this earth, but being even forced for their own subsistence to exert themselves far beyond the brute creation, are necessarily led to make a farther inquiry, and that with a labour beyond the contemplation of the benevolence of the Almighty. To those creatures who have only this earth to exist in, food and raiment are afforded without labour or attention, during the short period of their lives. It is not sufficient for the farmer to look where grain grows naturally; it is necessary to try, with an infinite variety of applications that may be made to the ground, to produce crops superior to those which would arise in it without any cultivation. It is necessary for the hunter not only to observe the natural history of wild beasts, but also to try by what means he can engage them to fall into his toils. It is necessary for the fisherman, besides admiring the multiplicity of fish, to be able to contrive either to entangle or surprize them into his nets. In many

other cases, it is necessary for mankind not only to contemplate those things which happen naturally, but he is likewise constrained to form projects of his own, and to contrive means of putting both mind and matter in circumstances foreign to what would naturally arise in them, and contemplate the effects; and this we call experiment.

"Thus observation and experiment are the sources of all the knowlege of mankind.

"Man seems to have a degree of pride planted in his nature, which prompts him constantly to consider himself as being far superior to what he actually is, which instinct is the surest proof that he is to be very superior indeed.* But as all the virtues of man are ballanced by opposite imperfections; the pride of experiment has often thrown science into confusion, instead of advancing its progress. An experiment to prove a thing otherwise demonstrable is totally superfluous, and not only superfluous but fallacious."

Another circumstance which injures philosophical pursuits, and retards their progress, is the neglect of old principles as soon as new ones are assumed, as if their efficiency ceased immediately, like that of old ministers of state upon the introduction of new ones. If the placita of their predecessors were not lost sight of or neglected, they would sooner attain the end of their inquiries, than by being so intent on their own discoveries, as to neglect, as rubbish, all those circumstances that were formerly of such moment.

That light and fire are substantially the same, or different modifications of the same fluid, is evident

* Every vanity of man shews his degraded state, and from what dignity he has fallen. Did not man find and feel that he is a poor prisoner in the valley and shadow of death, he would no more have any of those instincts alluded to above, nor any reaching desire after all the beauties of fallen nature, than the ox to have his pasture inclosed with beautiful walls and painted gates.

from their commutability, or their reciprocal generation of each other. For, as fire necessarily generates light, and thus discovers itself to the sense of seeing as infallibly as to the feeling; so light conveyed to a focus, constitutes pure fire. Light and heat are propagated by the same laws; they act in straight lines, they diffuse themselves from a center outward, their powers decay according to their distances from the centers from which they are irradiated, they are subject to the same laws of reflexion.

Notwithstanding that the phenomena of nature, which tend to ascertain beyond doubt that the matter of common light or fire pervades all nature and fills all things, are exceeding numerous and obvious to every eye; yet the whole as been overlooked as an accidental filtration, implying no consequences, nor interfering with the various properties of bodies, notwithstanding its access to their innermost penetralia.

Our globe itself seems to be nothing more than an accumulation of terrestrial materials, introduced into the boundless ocean of the solar fluid, for a theatre on which it may display its inexhaustible power and energy; the mass being so disposed and arranged by its Author, as to become a seminal bed of materials, to be pierced and animated by light; and from which materials, light can extricate all the forms, and generate all the powers in nature.

Without this principle, all that we call body would remain for ever an inactive, passive incoherent calx. Water by its transparency evidences to your senses, that light has free access into and through its substance. By the volatilization of water, it is equally evident, that light or fire has not only access to its interstices, but penetrates and occupies its similar elementary particles; in the conformation of which particles the character of water consists. These particles could not be rendered volatile but

by internal dilatation, nor could they be dilated but by something that reached their internal parts; they have their individuality as separable elementary particles, as well as their similarity of character preserved by the etherial principle possessing them. If the natural life of all things depends upon the activity communicated to them by the sun, is it not evident that it is the same influence which must generate and maintain that life in all its specific characters, in every being according to its kind?

When the sun is said to rule over the day, and to have been made for this end, what else can be understood but that he acts as a vicegerent, and is invested with a mechanical power of giving light, life, and motion, to such objects as are ordained to receive his impressions? All nature revives and puts on a new face, when he approaches us in spring; and sinks into a temporary death, at his departure from us in the winter. That he acts in a mechanical manner, is also certain, because a chain of matter is continued all the way from the agent to the object. His power consists not in any immaterial quality, because it observes the same geometrical law with the diffusion of its light; and his efficacy upon the production of the earth is greatest, when the greatest angle is formed between the horizon and his rays. A good telescope will shew you what changes are produced in the refraction of the atmosphere, and what a tumult arises in the air from the agitation of the sun-beams in the heat of noon-day; the heaven seems transparent and undisturbed to the naked eye, while a storm is raised in the air by the impulse of light, not unlike what is raised in the waters of the sea by the impetuosity of the wind. It increases with the altitude of the sun; and when the evening comes on, it subsides almost into a calm.*

* *Chaptal's* Elements of Chemistry.

Light is now no longer considered by chemists* merely as an ideal substance; they perceive its influence in many of their operations, and, as it modifies many of their results, they find it necessary to attend to its action.

The effects of light are more evident in the phenomena of nature, than in the experiments performed in the laboratory.

Light is absolutely necessary to plants; vegetation does not succeed without it; deprived of this principle, they become pale, languish, and die. It appears from incontestible facts, that the root of the most variagated flower, though excluded from the external air under a glass vessel, will, provided it be daily exposed to the light of the sun, arrive at its utmost perfection both with respect to fragrance and colour; but if the process be reversed, and the air admitted without the light, the flower may, perhaps, grow to its natural size, but we shall in vain look for that beautiful variety of vivid colouring, and that exquisite perfume which nature bestows on every individual of the species, when permitted to imbibe and enjoy the solar beam.

The same fact is further evinced by a variety of experiments by several French academicians, in which the light was admitted to one part of a plant, and excluded from the others. The invariable effect of this was, that the part exposed to the sun was of a lively green, while that which was shaded continued of a disagreeable pale colour. Nay, so powerful are the effects of the sun's light on vegetables, that, when deprived of it, their taste and other native properties undergo such a change, that some, in their nature poisonous, become a safe and wholesome food. Without the influence of light, vegetables

* *Jones's* Essay on the First Principles of Philosophy,
—— Physiological Disquisitions.

would exhibit one lifeless colour, and are deprived of their beautiful shades by the interception of the luminary fluid. On these principles, celery, endive, and other plants are bleached.

All these circumstances evidently shew, that there is something in light absolutely necessary to vegetable life. Hence all plants shew a remarkable sensibility to the light; they expand their leaves and open their flowers to the sun, and close them the moment he disappears. Many accurate experiments prove, that it is not the heat, but the light of the sun, that causes them to turn to him. A plant in a room where there is a fire, turns its flowers to the light which comes from the colder side.

Many experiments shew, that the change of position in the leaves of plants, at different periods of the day and night, is entirely owing to the agency of light. The upper surfaces of leaves, which are supposed to be their organs of respiration, seem to require light as well as air; for plants, which grow in windows on the inside of houses, are as it were solicitous to turn the upper sides of their leaves to the light. This agent is subtile, active, and penetrating; by the smallness of its constituent particles, it is capable of entering all bodies; and, from its activity, of producing great effects and considerable changes therein.

Vegetables are not only indebted to the light for their colours, but likewise for their smell, taste, combustibility, maturity, and the resinous principle, which equally depend upon this fluid.* The aromatic substances, resins, and volatile oil, are the inheritance of southern climates, where the light is more pure, constant, and intense. All these circumstances, it is hoped, will concur to make you attentive to the nature and office of the sun. The

* *Chaptal*'s Elements of Chemistry.

sun is the united power of fire and light, and by these powers calls forth from the earth a beautiful variety of vegetable life, cloathing them with its own brightness and beauty, and rendering them holders and displayers of all its colours, powers, and virtues.

The influence of light is evident on other animated beings: worms and grubs, which live in the earth or in wood, are of a whitish colour. Birds, and flying insects of the night, are likewise distinguishable from those of the day by the want of brilliancy in colouring; and the difference is still more marked between those of the north and of the south.

A very astonishing property of light upon the vegetable kingdom is, that when vegetables are exposed to open day-light, or to the sun's rays, they emit oxygene or vital air.*

It has been proved, that the sun does not act in the production of this phenomenon as a body which heats. The emission of air is determined by the light; pure air is, therefore, separated by the action of light, and the operation is stronger as the light is more vivid. It would seem that light favours the work of digestion in the plant, and that the vital air, which is one of the principles of almost all the nutritive juices, more especially of water, is emitted when it finds no substance to combine with it in the vegetable. Hence plants, whose vegetation is the most vigorous, afford the greatest quantity of air.

By this continual emission of vital air, the Author of nature incessantly repairs the loss thereof occasioned by respiration, combustion, and the alteration of bodies, including every kind of fermentation and putrefaction: in this manner the equilibrium is always maintained between the constituent parts of the atmosphere.

* Lecture XI.

Scheele and *Berthollet* have shewn, that the absence or presence of light has an astonishing effect upon the result of chemical experiments. Light disengages vital air from several fluids, such as the nitrous acid, dephlogisticated marine acid, &c. it reduces the calces of gold, silver, &c. it changes, according to Mr. *Berthollet*, the nature of oxygenated muriates. M. *Chaptal* has shewn, that it determines the phenomena of vegetation, exhibited by saline solutions. These circumstances shew the importance of light, and how much its agency in nature should be attended to by every philosopher: heat often accompanies light, but some of the phenomena we have mentioned cannot be attributed to mere heat; heat may indeed modify them where it exists, but it is not the producing cause.

There are many instances, where the action of the solar light contributes to the destruction of colour, and, instead of extricating vital air, fixes it, and produces a kind of combustion. In like manner phosphorus, while in the dark, is not affected by the oxygenated muriatic acid, even assisted by heat; but, when the action of light concurs, it is converted into phosphoric acid.*

A variety of facts shew, that vital air is capable of whitening or rendering paler the colouring matter with which it unites, perhaps by having produced on them the effects of a slight combustion.† Vital air has considerable influence on the colouring particles of vegetables; these are formed chiefly in the leaves, flowers, and inner bark of trees, and by degrees they undergo a slight combustion: hence most trees contain fawn-coloured particles.

* *Berthollet's* Art of Dyeing.

† See what has been said on incipient ignition, under the article of Phosphori.

The manner in which the sun acts upon colours may be seen by examining the appearances presented by a solution of the green part of vegetables in alcohol.

If such a solution, which is of a fine green colour, be exposed to the light of the sun, it very soon acquires an olive hue, and loses its colour in a few minutes. If the light be weak, the effect is slower; and in perfect darkness the colour remains without alteration, or requires a great length of time.

M. *Berthollet* inverted over mercury a bottle half full of this green solution; when the colour was discharged, the mercury was found to have risen in the bottle, and consequently vital air had been absorbed, the air having united with the colouring matter; on evaporating this liquor, its colour was immediately rendered darker, and became brown: the residuum was black, and in the state of charcoal.

The light seemed therefore to have produced its effect by favouring the absorption of vital air, and the combustion of the colouring matter; the marks of combustion are not evident at first, but by the assistance of heat the liquor becomes brown, and leaves a black residuum. If the vessel containing the liquor holds no vital air, the light has no effect on the colouring matter.

The effects of light on the colour of wood have been long observed; it preserves its natural appearance while kept in the dark, but when exposed to the light it becomes yellow, brown, or of other shades. M. *Senebier* found, that the changes were proportioned to the brightness of the light, that several folds of ribbon were required to defend the wood completely, when a single leaf of black paper was sufficient; that when paper of any other colour was substituted, the change was not prevented; that a single covering of white paper was insufficient, but that two intercepted the action of the light.

These observations are important, as they prove that light can pass through coverings that appear to be opake, and exert its energy at some distance within.

M. *Berthollet* put tincture of turnsole in contact with vital air over mercury; one parcel he placed in the dark, the other was exposed to the light of the sun; the former continued unchanged for a considerable length of time, and the vital air was not diminished; the other lost much of its colour, became red, and the air was in a great measure absorbed, and a small quantity of fixed air was produced, which no doubt had occasioned the change of colour from blue to red.

This observation may lead us to form an idea of some of the changes produced by a particular disposition of the component parts of vegetable substances, when by the combination of vital air they undergo the effects of a slight combustion, which may generate an acid; as in the leaves in autumn, which grow red before they become yellow, and in the streaks observable in flowers, whose vegetation is growing languid.

The success of the present age in arts, experiments, and new systems, is very apt to elate the minds of men, and make them overlook the ancients. But notwithstanding the encouragement and purse of princes, and the united endeavours of great societies in these later ages, have extended experimental and mechanical knowledge; yet it must be owned, the ancients were not ignorant of many things, which are now more generally, though not first known. Their notions of fire and light, the result of observation, were for the most part just. They considered the principle of motion and vegetation as delibations from the invisible fire of the universe, which, though present to all things, is not nevertheless one way received by all; but variously imbibed, attracted, and secreted by the fine capil-

laries and exquisite strainers in the bodies of plants and animals, and is thereby mixed and detained in their juices. They supposed the elaborate spirit, whereon the character, distinguishing virtue, and properties of the plant depend, to be of a luminous and volatile nature.

It was from an etherial and luminous fluid that they derived the many and various qualities, virtues, odours, flavours, and colours, which distinguish natural productions; conceiving that the original particles productive of these properties were diversely separated, and attracted by the various subjects of the animal, vegetable, and mineral kingdoms, which thereby become classed into kinds; and indeed with those distinct properties which continued till their several forms, or specific proportions of fire, returned into the common mass.

They considered all the appearances of fire, even in earthly things, as something of a heavenly, exalting, and glorious nature; as that which disperses death, darkness, and grossness, and raises up the power and glory of every life; that it was seldom seen in this world but as a destroyer, a consumer, and refiner of grossness; as a kindler of life and light out of death and darkness; that so much as any thing had of light, so much it had of heaven; and that this was rendered evident in the power of the sun, and manifested in the softness of sounds, the beauty of colours, the fragrance of smells, and the richness of taste.

Before I finish this Lecture, I must make a further observation on colour, on account of the mischievous inferences deduced from the Newtonian theory, by *Voltaire*, and some other infidel writers. These men suppose that light and colour, as apprehended by the imagination, are only ideas in the mind, and not qualities that have any existence in matter. Strange as this may seem, it has been uni-

versally received, and considered by some as one of the noblest discoveries of modern philosophy.

By colours, all men, who have not been tutored in this school, understand not a sensation of the mind, which can have no existence when it is not perceived, but a quality and modification of bodies, which continues the same whether it be seen or not. The scarlet rose, which is before me, is still a scarlet rose when I shut my eyes, and was so at midnight when no eye saw it; the colour remains when the appearance ceases; it remains the same when the appearance changes; for when I view this scarlet rose, through a pair of green spectacles, the appearance is changed; but I do not conceive the colour in the rose to be changed. To a person in a jaundice it has still another appearance, but he is easily convinced the change is in his eye, not in the colour of the object. We can by a variety of optical experiments change the appearance of figure and magnitude in a body, as well as that of colour; we can make one body appear to be ten. But no man believes the multiplying glass really produces ten guineas out of one; in like manner, no one believes the coloured glass changes the real colour of the object seen through it, when it alters the appearance of that colour.

Colour is not a sensation, but a secondary quality of bodies, whereby in fair day-light they exhibit a certain and well-understood appearance; and there is a real permanent quality in bodies, to which the common use of this word agrees. Had modern philosophers given, as they ought to have done, the name of colour to the cause instead of to the effect, they would not have set philosophy apparently in contradiction with common sense; for they must then have affirmed with the vulgar, that colour is a property of bodies, and that there is nothing like it in the mind. Their language as well as their sen-

timents would have been perfectly agreeable to the common apprehensions of mankind, and true philosophy would have joined hands with common sense.*

Instead of seeking objections against revelation from every appearance in nature, the true philosopher finds abundant ground therein to confirm and establish his faith; he learns from the adaptation of objects to the senses, the absurdity of those infidels, and their want of knowledge in the human understanding, who require for conviction a stronger evidence in the objects of faith, than is to be offered for those of the other faculties.

In examining the objects of various parts of intellect, do not we find men at a loss to prove in what manner they exist? Do they suspend their assent to the reality of a rose, till they can explain why the leaves are of a different colour, odour, and shape, from those of the lily? or why they are of any particular smell, shape, or colour? Is it an objection to the evidence of the eye-sight, that the sounds of a violin are imperceptible by that organ? or because neither form nor sound are the objects of reason, that neither of them exists? Would not a geometrician treat with contempt the person who should deny the reality of the properties of a square, because they are irreconcileable with those of a circle? All that is required in these instances, is a consentancons disposition in the objects and the faculties to impart and receive those ideas, and the mind rests convinced of their realities.

The utility and pleasure which are derived from the senses are the great proofs which satify men of the reality of the objects of them. He, whose eyesight prevents him from running over a precipice, whose ears are delighted with the powers of har-

* *Reid*'s Inquiry into the Human Mind.

mony, can entertain no doubt of the existence of those objects; and whoever should attempt to prove, that the first was not seen, and the latter not heard, would inevitably render himself an object of ridicule. And is not a man equally ridiculous, who denies that the objects of faith are real, though he is every day acquiring happiness, and obtaining security, as the result of them? The adaptation of the doctrines of faith to the nature of man, and the superior utility arising from it, are the strongest proofs of its divine original; their principles correspond to the faculties and wants of human nature, and its precepts to their welfare.

To deny these proofs would be to reject all moral evidence, and even the existence of a Deity. When we perceive all parts of matter fitted to the uses of creation; when we see that rain and sun are necessary to vegetation, and that the order and course thereof is such, that they never fail the purposes of their intention; is it possible to deny the providence of a Supreme Intelligence? In like manner, when it is discovered, that all parts of our religion coincide as perfectly with the nature of man and his welfare, is it not equally absurd to reject it as proceeding from the same source?

Whoever consults the sensations of his own mind, will feel the evidence of the hereditary evil of man as evincing, as the dry leaf is expressive of its having been in a more perfect state. What are the presentiments and presages of the soul, but the remains of a more perfect intelligence? And what is that abatement of pleasure which enjoyment tastes compared with the felicity imagination preconceives, but an indication of the defect in the human faculties? Like the evanescent colours of a declining tulip, they pronounce their former excellence.

The sense of degradation, and of its being irremediable by the powers of man, creates those desires in

the human breast which are constantly yearning after a better state, and the belief of the necessity of a more perfect being to restore it. Here the idea of infinite mercy, inseparable from the Divine Being, leads the soul to see that its redemption can only be accomplished by the Supreme Being. Thus you may perceive, that the truths of christianity are obvious and plain; they speak the language of nature; and all nature is expressive of the sense and sound thereof; and points out the necessity of a Redeemer, whose existence and influence is as extensive as nature itself.

To shew that nothing under him, "in whom we live, and move, and have our being," could redeem us, our Redeemer, when he had shrouded his beauty with the veil of mortality, gave hourly and ocular proofs of his Godhead by the extent of his power in and over all things. "In his word was life, in his breath was healing, and sickness grew sound at his sight; the lame sprang up at his bidding, by him the deaf ear was opened, and the dumb tongue loosed to utterance; he poured the beams of his light upon the new opening eyes of the blind-born gazer; death fled before him, and amidst the tombs his word was life and resurrection; the tempest heard his voice and was still; the earth trembled with reverence; and the sea spread itself as a carpet beneath the foot of her Creator.

——————" Yet
" Even all his mighty works to me import,
" But as they greatly serve to authorize
" The mightier words he uttered—as the eye
" Bears witness to the light, or the charm'd ear
" To tuneful undulation; so the heart
" Strikes unison to his great law of LOVE,
" And proves his mission all DIVINE."

LECTURE XXII.

ON TELESCOPES.

In our last Lectures, I endeavoured to render plain and easy to your comprehension, some of the great discoveries of Sir *Isaac Newton*, who surpassed himself in his Theory of Light and Colours, as much as he had exceeded others in his Principia. Both these works give testimony to the depth and clearness of his intellect, his skill in conducting experiments, and the comprehensive force of his mind. But far as he has penetrated into the recesses of light, the same Lectures must have convinced you, that many appearances are yet unexplained, many difficulties are yet unexplored; and that the instances are numerous which prove, that the inward constitution, the real causes, and connections of the most obvious phenomena, are beyond your apprehension.

Vanity in any man is weakness; but a vain philosopher is the most absurd among men, for every new discovery demonstrates his imbecility; every new effect that is brought to light, serves only to convince him of innumerable others which remain concealed, and of which he had no previous knowledge: the works of God are too vast, and of too large an extent for our capacities. There is such an expanse of power, wisdom, and goodness, in the formation of the world, as is too mighty for our grasp, too much for us to comprehend. Power, wisdom, and goodness, are manifest to us in all those works of God which are within our view: but there are likewise infinite stores of each poured forth throughout the immensity of the creation, no

part of which can be understood without taking in its reference and respect to the whole, and this is beyond the reach of human faculties. To whom hath the root of wisdom been revealed? or who hath known her wise counsels? There is one wise and greatly to be feared, the Lord sitting upon his throne. He created her, and saw her, and numbered her, and poured her out upon all his works.

These reflexions naturally occur to the mind when it contemplates the discovery of the telescope, and the advantage arising from it: for who, reasoning *a priori*, could have imagined that the refraction of light in a glass, the same power by which a straight rod appears crooked in water, whereby vision is variously distorted, and whereby we are liable to innumerable deceptions, should ever be so circumstanced as to extend the boundaries of sight, and enable us to distinguish objects too remote for natural vision? Yet such are the powers science has bestowed, that by glasses, properly adapted to each other, we as it were contract space, and bring within our ken the grander objects of the universe; and are enabled to extend our inquiries beyond the boundaries of the solar system.

If *Pliny*, in regard to *Hipparchus*, could extravagantly say, *Ausus rem Deo improbam annumerare posteris stellas*, what would that pompous historian of nature have said, had it been foretold him, that in the latter days a man would arise, who should enable posterity to enumerate more new stars, than *Hipparchus* had counted of the old; who should assign four moons to Jupiter, and in our moon point out higher mountains than any here below; who should in the sun, the fountain of light, discover dark spots as broad as two quarters of the earth, and by these spots ascertain his motion round his axis; who, by the varying phases of the planets, should compose the shortest and plainest demonstration of the solar

system? Yet these were but a part of the annunciations to the world of a single person, of *Galileo*, of unperishing memory! To him, his cotemporary and rival in fame, Lord *Bacon*, ascribed the invention of *perspicilla*, for so at first were called the telescopes, and in a figurative strain thus expressed himself concerning them: "With these *(perpiscilla)* which *Galileo*, by a memorable effort of genius, hath discovered, we are enabled, as with some small sailing vessels, to open and keep up a nearer commerce with the stars."

Nor did the celestial commerce cease with the acquisitions of *Galileo*, but has been extending ever since the time that that great man first turned his glasses to the heavens.* In our own day, the energy and philosophic enthusiasm of *Herschel* has enlarged the boundaries of astronomical knowledge, added a new planet to our system; the heavens have, as it were, increased under his eye; and 44,000 stars, seen in the space of a few degrees, seem to indicate that seventy-five millions may be discovered in the expanse exposed to human investigation.

What is necessary for the conduct of our animal life, the bountiful Author of nature has made manifest to all men. But there are many other choice secrets of nature, the discovery of which enlarges the power and exalts the state of man; these are left to be discovered by the use of our rational powers; they are hid, not that they may be always concealed from human knowledge, but that we may be excited to search for them: this is the proper business of a philosopher; and it is the glory of a man, and a reward for his labour, to discover that which has been thus concealed.

* Sir *John Pringle*'s Discourses, p. 228.

Thus in the subject before us, our eyes are incapable of discerning objects, either very small or very distant; but the Creator has given properties and qualities to matter by which it may procure us these advantages: he elevated the understanding from one degree of knowledge to another, till it was able to discover these assistances for our sight. It is to the same power, therefore, who created the objects of our admiration, that we are ultimately to refer the means of their discovery; and whatever we find out by their means, becomes a fresh source of praise to him from whom we receive every blessing.

The very great importance of the telescope has made the first discovery of it an interesting object of inquiry; but no research has been able to ascertain either the exact period when it was first found out, or who was the inventor. It has been by some, and with no small degree of probability, attributed to the famous friar, *Roger Bacon*, before the year 1300, and it is worth your while to be acquainted with some of his expressions. "Lenses and specula may be so figured, that one object may be multiplied into many; that those which are situated at a great distance may be made to appear very near; that those which are small may be made to appear very large, and those which are obscure very plain; and we can make stars to appear wherever we will." These and other expressions and tracts of this author seem to indicate, that he was well acquainted with the nature, construction, and use of telescopes, and all the glasses which compose them; but some modern critics in the science not only deny him the invention, but even the knowledge of any such construction, as we at present call telescopes, though he mentions the refractions of the sun's rays through a glass sphere; but as he does not say, *totidem verbis*, that he ever viewed an object through such a sphere,

Dr. *Smith* supposes that he had no experience of its magnifying power. In the same manner, had *Seneca* described his glass ball, filled with water, only as a burning-glass, it might have tempted us to argue that he knew nothing of its use in magnifying letters; but he has precluded conjecture by declaring the contrary. He might know more than is spoken of; the mathematicians and workers in glass of those days might know more than he did. From the foregoing and other expressions of our countryman, Friar *Bacon*, there is little doubt but that he was acquainted both with spectacles and telescopes.

"Friar *Bacon*," says the Rev. Mr. *William Jones*,* "may be considered as the first of English philosophers; his profound skill in mechanics, optics, astronomy, and chemistry, would make an honourable figure in the present age; but he is entitled to further praise, as he made all his studies subservient to theology, and directed all his writings, as much as could be, to the glory of God. He had the highest regard for the sacred scriptures, and was persuaded they contain the principles of all true science. He had a liberal way of considering things, not adhering servilely to his subject, but using all the sciences of which he was master to illustrate each other. It is very unjust to speak of philosophy, as if it was unknown till the last century, when in reality a scholar furnished with no materials, but such as might be extracted from Friar *Bacon*'s works, would yet be a very considerable person, and entitled to no small degree of fame among the literati of the present age. He would excel as a mathematician, experimentalist, physician, chemist, artist, astronomer, philosopher, and divine."

* *Jones's* Physiological Disquisitions, Introduction.
Duten's Inquiry into the Origin of Modern Discoveries.
Biographia Britannica.

Men of learning have been divided in their opinions concerning the optical knowledge of the ancients; some are so swallowed up by an admiration of the discoveries that have been made in the last and present century, that they have been tempted to pass sentence upon the ancients, before they knew what the ancients have said for themselves. It is said, indeed, that if dioptric glasses were anciently in use, it is strange we find them so seldom mentioned in their writings. This may be hard to account for, but it is unsafe to draw a positive conclusion from negative evidence. The accounts we have of many ancient works of art are so much broken by the injuries of time, the ambiguities of language, the succeeding interests of different sects of philosophers, the barbarism of succeeding ages, that it is now very difficult to establish the supposition by satisfactory proofs.

If we argue by inference, the case will be a little altered. The cabinets of the curious contain some very ancient gems, of admirable workmanship, the figures on which are so small, that they appear beautiful through a magnifying glass, but altogether confused and indistinct to the naked eye: and if they cannot be viewed, how could they be wrought without the assistance of glasses? How could it be known, that the moon has a form like that of the earth; that it has plains, hills, and vallies in it? When it is seen through a telescope, the disposition of light and shade render this evident, agreeable to the common rules of perspective; but no such thing appears to the naked eye. How could it be known that the *via lactea* arises from the combined rays of an infinite number of small stars?* But above all,

* It is only by reflectors of large apertures, that an innumerable quantity are made clearly visible; and there is scarcely any part of the hemisphere to which you turn the instrument, but many are seen, which are not visible through smaller apertures. EDIT.

how came it to be asserted, *that the sphere of the fixed stars is so immense, that the circle of the earth's annual orb bears no greater proportion to it than the center of any sphere bears to its whole surface?* This discovery does so far exceed the comprehension of the human mind, that it was not asserted after the revival of the Pythagorean scheme, till Dr. *Bradley*, by a course of the most accurate observations that ever were made with a telescopic apparatus, reduced the annual parallax of the fixed stars to an insensible quantity.

If leaving the ancients we return to the moderns, we find the time of the invention, and the name of the inventor, are still involved in obscurity. By some it is ascribed to *James Mœtius*, a Dutchman; by others to *John Leppersheim*, of Middleburg: but *Borellus*, in a circumstantial and apparently well-authenticated account, attributes the invention to *Zacharias Jansen*, of Middleburg, about the year 1590. *Jansen* was a diligent inquirer into nature, and being engaged in these pursuits, and trying what advantages could be derived from combining lenses, fortunately discovered the telescope.

The wonderful effects of this instrument soon reached *Galileo*, who, setting himself to work, contrived an instrument to effect the same purpose. As this subject is so curious and interesting, I think you will be pleased with his own account of it, as published in a book intitled, *Nuncius Siderius*, in March 1610. "Near ten months ago," says he, "it was reported that a certain Dutchman had made a perspective, through which many distant objects appeared as distinct as if they were near; several effects of this wonderful instrument were reported, which some believed, and others denied: but having had it confirmed to me a few days after by a letter from the noble *John Badoviere*, at Paris, I applied myself to consider the rationale thereof,

and by what means I might contrive a similar instrument, which I afterwards attained to by the doctrine of refraction; and first I prepared a leaden tube, to whose extremity I fitted two spectacle-glasses, both of them plane on one side; on the other side, one of them was spherically convex, and the other concave. I saw objects appear pretty large, and pretty near; they appeared three times nearer, and nine times larger in surface than to the naked eye: and soon after I made another, which represented objects above sixty times larger; and at last, having spared no labour or expense, I made an instrument so excellent as to shew things almost a thousand times larger, and above thirty times nearer than to the naked eye.

If the true inventor is he who makes discovery by reasoning *a priori*, and descending from established principles to their consequences, *Galileo* may be considered as the real inventor of the telescope; but the use he made of it does him more honour than the invention: the instrument was at first, in Holland, a mere article of curiosity, not an instrument of science; himself being amply rewarded by prevailing over the difficulty of the subject, and with new discoveries which enlarged the territories of reason.

OF REFRACTING TELESCOPES.

By a telescope is usually signified an instrument that renders the view of distant objects more perfect; or, in more general terms, which represents distant objects under a larger angle than that under which they appear to the naked eye.*

* When constructed entirely by glasses, it is called a refractor; when by metallic speculums, a reflector. Edit.

When the distance of the object is very considerable, the effects may all be referred to the same distance, and a telescope may be said to enlarge an object just as many times as the angle under which it represents it is greater than that under which it appears to the naked eye. Thus the moon appears to the naked eye under an angle of about half a degree; consequently, a telescope magnifies 100 times, if it represents the moon under an angle of 50 degrees; if it magnified 200 times, it would exhibit the moon under an angle of 100 degrees; and the moon would appear to occupy more than half the visible heavens, of which the whole extent is only 180 degrees.

It is a common expression, that telescopes bring objects nearer; but this expression is equivocal, admitting of two different significations. The one is, that looking through a telescope, we estimate an object to be as much nearer to us as it is magnified by the telescope. But I have already shewn you, that we can form no certain estimate of the distance of an object but by the judgment, and that our judgment deceives us when the objects are beyond a certain distance; and in the present instance, losing all those subjects of comparison on which it is founded, will deceive us more. The other meaning applied to the expression is, that the telescope represents the objects as large as they would appear if we were so much nearer to them; this latter meaning is more conformable to the truth than the preceding, for you must know, that the nearer we approach to an object the larger is the visual angle. When you look, however, at a well known object, as a man, at a great distance, and he is seen under a larger angle, we are led to think him so much nearer, because then he would really appear under a greater angle; but with respect to objects less known,

as the sun and moon, there can be no estimation of distance.

One principal end of telescopes is to enlarge or multiply the angle under which objects appear to the naked eye, and they are estimated according to this effect, and are said to magnify five, ten, or any other number of times, according to the nature and construction of the telescope.

This diagram, *plate* 6, *fig.* 13*, represents the glasses of a small Galilean telescope; the convex lens, PP, towards the object, the concave glass, QQ, is applied to the eye; on this account the one nearest to the eye is called the eye-glass, that towards the object is called the object-glass. These glasses are situated upon the same axis AB, which passes through the center of the glasses, and to which they are perpendicular. The focal distance, or focus of the convex glass, should be longer than that of the concave, and the lenses should be so disposed, that if AF be the focal distance of the convex lens PAP, the focal point of the concave glass should fall upon the same point F. Thus the interval, AB, between the two glasses, is the difference between their foci, AF being the focal distance of the object-glass, and BF that of the eye-glass. When the glasses are so placed, a common eye will see distant objects distinctly, and will magnify in the same proportion that the line, AF, exceeds the line BF. Thus, supposing the focus of the object-glass to be six inches, and of the eye-glass to be one inch, the interval between them will be five inches; the length of the telescope and the objects will be enlarged six times, that is, it will appear under an angle six times greater than what they do to the naked eye.

After having explained to you the manner in which the glasses are to be disposed, in order to

produce the desired effect, it remains for me to shew you why they represent the objects distinctly, and why they are magnified as many times as the line, AF, exceeds that of BF. With respect to the first, I must remind you of what has been before observed, that we see objects best when the rays that proceed from them fall upon the eye and are nearly parallel to each other.

This observation being attended to, you must now consider another diagram, *plate* 6, *fig*. 14. Let V be a point in the object towards which the telescope is directed, and as it is supposed to be very distant, the rays proceeding therefrom may be considered as parallel to each other; those therefore that fall upon the object-glass, QAQ, will be united at its focus F, and being convergent there, will not be adapted to produce distinct vision for a common eye. Now it being the property of a concave glass to render rays more diverging, or to diminish their convergence, it will refract the rays QR, QR, so as to render them parallel to each other; so that instead of uniting at F, they will proceed in the direction RS, RS, parallel to the axis ARF, and thus the telescope will be fitted for distinct vision.

I have now to explain the principal effect of telescopes, that is, their magnifying power; a subject which I hope to render so clear, that no doubts shall remain on your mind.

1. Let Ee, *plate* 7, *fig*. 3, be the object placed on the axis of the telescope, which passes through the center of the two lenses. Ee is to be considered as at an infinite distance.

2. If the eye placed at A look at this object, it will see it under the angle EAe, called the visual angle. What we have therefore to prove is, that in looking through the telescope, it will appear

under an angle as much larger than this, as the focal distance of the object-glass exceeds that of the eye-glass.

3. As the effect of all the glasses consists in representing the object in another place, and of a certain size, all we have to do is to examine the different images, the last of which forms the object immediately viewed by means of the telescope.

4. Now the object, E e, being at an infinite distance from the convex lens PAP, its image will be represented behind the glass at F f, and AF will be the focal distance of this glass; the size of this image, F f, is determined by a straight line from the extremity, e, of the object through A, the center of the lens; consequently this image is inverted, and as much smaller than the object, as the distance, AF, is smaller than the distance AE.

5. Now this image, F f, is to be considered as the object with respect to the eye-glass, Q B Q, since the rays that fall upon this glass are those which would form the image F f, but that they are intercepted in their passage by the concave glass Q B Q; so that though the image is only imaginary, the effect is the same as if it were real.

6. The image F f, which we may now consider as an object, being at the focal distance of the lens Q B Q, will be transported to an infinite distance by the refraction of the glass. This new image is marked in the figure by G g, of which the distance, AG, should be considered as infinite; and the rays being a second time refracted by the glass Q B Q, will continue the same direction as if they came from the image G g.

7. This second image G g, being the object that is seen by him who looks through the telescope, we must consider its size. Now as it arises from the first image F f, and from the refraction of the glass Q B Q, draw according to the general rule from B,

the middle of the concave glass, a line passing through f, the extremity of the first image, and it will mark at g, the extremity of the second image.

8. Now as the spectator applies his eye at B, and as the rays that fall upon his eye are received as if they come from the image G g, it will appear under the angle, G B g, evidently larger than the angle E A e, under which the object, E e, appears.

9. To compare these angles, I must inform you, that the angle, EA e, is equal to the angle FAf, and the angle, G B g, is equal to the angle, F B f. I have now therefore only to prove, that the angle, F B f, exceeds the angle FAf, as much as the line, AF, exceeds the line B f.

10. To prove this, we must have recourse to certain propositions deduced from geometry, concerning the nature of sectors. You probably remember, that a sector is an arc of a circle included between two radii; thus C M N, *plate* 7, *fig*. 4, is a sector of a circle; C M, C N, the two radii; M N, the arc or portion of the circumference. There are therefore three things to be considered in a sector: 1. The radius of the circle, as C M, C N. 2. The quantity of the arc M N. 3. The angle M C N.

11. Let us now consider the two sectors M C N, and m c n, *plate* 7, *fig*. 4, of which the radii, C M and c m, are respectively equal. Geometry proves, that in this case the angles, C and c, are in the same ratio as the arcs M N and m n; or in other words, that the angle, C, is so many times larger than the angle c, as the arc, M N, is larger than the arc m n; or, in more general terms, when the radii are equal, the angles are proportional to their respective arcs.

12. In the two sectors, M C N and m c n, *plate* 7, *fig*. 5, the angles are equal, but the radii are unequal. The elements of geometry prove, in this case, that the arc, M N, is so many times greater than

the arc mn, as the radius CM is greater than cm; or that the arcs are proportional to the respective radii when the angles are equal. The reason is evident, for each arc contains the same number of degrees; but the degrees of a large circle are as much larger than those of a small one, as the longer radius exceeds the smaller one.

13. In the two sectors, MCN and mcn, *plate* 6, *fig.* 6, the arcs are equal, but the radii are unequal. Here the angle C, which answers to the longest radius, is the smallest, and that in the same ratio as the radii; or the angle, c, is so many times larger than the angle C, as the radius, CM, is larger than the radius, cm; or, in more general terms, the angles are reciprocally proportional to the radii when the arcs are equal.

14. The last article comes more immediately to our purpose, with the addition of this observation, that when the angles are very small, as is the case in small Galilean telescopes, the arcs MN and mn do not differ sensibly from their cords, or the straight lines MN and mn.

15. We may now return to the former diagram, *fig.* 3. The triangles FAf, FBf, may be considered as sectors, and the arc, Ff, as common to both; consequently the angle FBf exceeds the angle FAf, as much as the distance AF exceeds that of BF; or the object Ee will appear in the telescope under an angle as much larger than that under which it appears to the naked eye, as the focal distance of the object-glass exceeds that of the eye-glass, which was what I had to prove to you.

You will easily comprehend from what has been said, that very great advantages are not to be expected from a telescope constructed on this plan; for, in order to obtain any considerable magnifying power, it must be made very long, a circumstance that renders it inconvenient in use. Besides this,

there are other disadvantages, among which the smallness of the apparent field is the principal.

This naturally leads me to consider the nature of the apparent field, which is an article of great importance in all telescopes. When you direct a telescope towards the heavens, or any other distant object, the space discovered appears of a circular form, and no objects are seen but what are contained within this circle; so that if you are desirous of viewing other objects, you must change the position of the telescope; this circular space is called the *apparent field*, or simply the *field of view*. Hence you will readily conceive, that it must be a great advantage to have a telescope with a large field, and that a small field must be considered as a defect.

As a large field is a great perfection in a telescope, it is often necessary to measure the field: this is generally attained by measuring the number of degrees contained in the space taken in by the telescope, when directed to the heavens, or to some very distant object. Thus as the apparent diameter of the full moon is about half a degree, if a telescope only takes in the moon, we say its field is half a degree; but if you only see one-half of the moon, the field would only be a quarter of a degree.

But in order to judge rightly of the field of a telescope, you must take in the magnifying power; for it is a general principle, that the more a telescope magnifies, the smaller is the field: nature here prescribes the boundaries. Let PAP, *plate* 7, *fig.* 3, be the object-glass, QBQ the eye-glass of a telescope, EF the axis thereof, Ee an object at a great distance seen under the angle EAe, which represents half the diameter of the apparent field; which extends as much on one side the axis as on the other. The point, E, is the center of the field; the ray EA is not refracted as it passes through the middle of the glasses, perpendicular to their axis: in order, there-

fore, that this ray should enter the eye, the eye must be placed somewhere on the axis BF, behind the eye-glass, and so that the pupil may be on the line BF; this is a general rule with respect to all telescopes. Let us now consider the visible extremity, e, of the object; and of this it is plain that the extremity, e, of the object cannot be seen, unless the ray eA, proceeding therefrom enters the eye.

Let us then consider the direction of the ray eA; now, according to the laws of refraction, this ray is not refracted, because it passes through the middle of the object-glass A. This ray will therefore continue in the same direction to unite with other rays proceeding from the same point e, to form at f an image of the object represented by fF, the point f being the image of the point e of the object eE: but this ray meeting at m the concave glass, and not falling on the middle thereof, will be refracted; and instead of proceeding to f, will proceed in the direction mn, more diverging from the axis BF. You remember that the object-glass forms an inverted image of the object at Ff, and that Ff becomes the object with respect to the eye-glass, by which it is transported to Gg. The distance, BG, is as great as that of the object, because Ff is in the focus of the eye-glass.

With respect to the size of the images, the first, Ff, is determined by the straight line, eAf, drawn from e through the middle of the glass, PAP; and that of the other, Gg, by a straight line fBg, drawn from f through B the middle of the eye-glass. The ray, Am, directed towards the point f, is refracted and proceeds towards mn, and this line continues backwards, passes by g, for the ray, mn, produces the same effect upon the eye as if it proceeded really from g. Now, as mn diverges from BF, where the pupil of the eye is placed, it cannot enter the eye, if it diverges further than the limits of the pupil of the

eye; so that in this species of telescope the field depends on the size of the pupil of the eye, and the larger this is the larger is the field; so that if the distance, Bm, does not exceed the diameter of the pupil of the eye, in order that this field may not be diminished, the eye should always be placed as near as possible to the eye-glass.

To determine then the size of the field in these telescopes, you have only to take the interval Bm equal to the semidiameter of the pupil, and then draw a line, mAe, from m and the middle of the object-glass, and this line will mark upon the object that extremity, e, which will be visible by the telescope, and the angle eAE will give the semidiameter of the field. From this it is very evident, that if the distance between the two glasses exceeds a few inches, the angle BAm will become very small, because the distance Bm is only about the $\frac{1}{20}$th of an inch. Now, in order to magnify much with these telescopes, the distance between the glasses must be considerably increased, in which case the field would be infinitely small; so that the extent of these telescopes is limitted by the nature of their construction, and the optician, in order to produce great effects conveniently, is obliged to have recourse to other kinds.

A SUMMARY VIEW OF THE PROPERTIES OF THE GALILEAN TELESCOPE.

1. The focal distance of the object-glass must be greater than that of the eye-glass, or it will not magnify an object.

2. The magnifying power is equal to the quotient arising by dividing the focal distance of the object-glass by that of the concave eye-glass.

3. The rays proceeding from the eye-glass to the eye are nearly parallel; if this does not suit the eye,

the tube containing the eye-glass must be put in or drawn out a little, till the object appears distinct.

4. The visible area of the object is greater, the nearer the eye is to the glass, and depends on the diameter of the eye's pupil and of the object-glass; the field of view is therefore very small.

5. If this telescope be long, the visible area is so small as to render it useless; this arises from the smallness of the object-glass; but if this be broader, the object will be coloured and confused.*

OF THE ASTRONOMICAL TELESCOPE.

The next kind, which is denominated the astronomical telescope, consists also only of two lenses, and both of them are convex. Let PAP, *plate* 6, *fig.* 15, represent the object-glass which is convex, and whose focus is at F; QQ, a smaller and more convex lens for the eye-glass, which is to be fixed upon the same axis EAFBO, so that its focus may coincide with the point F; holding the eye at O, so that the distance, BO, be nearly equal to the focal distance of the eye-glass. With a telescope constructed in this manner, objects will be seen distinctly, and magnified in the same proportion as the focus of the object-glass exceeds that of the eye-glass; but it represents all objects inverted, which does not lessen its value for astronomical purposes, but renders it inconvenient and improper for viewing terrestrial objects.

I have to explain to you, 1st. How this arrangement of glasses shews distant objects distinctly. 2d. Why it magnifies in the same proportion as the

* The common opera glass, and pocket achromatic perspective are a sort of Galilean telescopes; a six-inch one of the latter kind, with a change of four eye-glasses, in a brass mounting with a stand, &c. with the largest power applied, will shew the satellites of Jupiter, &c. EDIT.

focus of the object-glass exceeds that of the eye-glass, and exhibits the objects in an inverted position. And, 3d. Why the eye is not to be placed close to the eye-glass, as in the former construction.

1. The first article is proved in a similar manner to the same article in the preceding construction; the rays, cP, eP, which are parallel to each other, before they fall upon the object-glass, are thereby refracted and unite at its focus; in order therefore for distinct vision, the eye-glass must re-establish the parallelism of the rays, which is effected by placing the eye-glass so that its focus may be at F, and consequently the rays will proceed from it as parallel to each other, and fall upon the eye in that direction.

2. For the explanation of the second article, let us consider the object eF, *plate* 6, *fig.* 16, supposed to be placed at an infinite distance. The image of this object formed by the object-glass, at its focus, will be Ff; this image will be inverted, and become an object for the eye-glass, and being situated at its focus, the image will be at an infinite distance, suppose at Gg, AG being considered an infinite distance as well as AE. Now, to determine the size of this image, draw a straight line, Bfg, through B the middle of the lens, and the extremity, f, of the image. The second image is the immediate object of vision, and being at an infinite distance, will be seen under the angle GBg; but the object itself is seen under the angle, EAe. I scarcely need observe to you, that it is indifferent where the points A and B are taken, as the distance is considered as infinite. The triangles FAf, FBf, may, as in the preceding construction, be considered as sectors of a circle, the line, Ff, being an arc common to both, for the angles are so small that the chord may be taken for the arc; AF and BF are the respective radii, and the arcs are equal; and of course, as I

have proved before, the angles FAf, or EAe, and FBf, or GFg, are in the same ratio as the radii BF and AF. Therefore the angle GBg, under which the object is seen by the telescope, is so much larger than the angle EAe, under which the object is seen by the naked eye, as AF is larger than BF.

3. With respect to the place of the eye, the proper situation thereof is determined by the field; for if you remove it either way from the focus of the eye-glass, the field is diminished. It is a great advantage in telescopes of this construction, that by removing the eye from the eye-glass, the field may be to a certain degree increased; and it is owing to this that the magnifying power of these may be so much increased, which will be evident by the following considerations:

1. Let Ee, *plate* 6, *fig*. 16, be the object at an infinite distance, e, the extremity visible by the telescope, whose glasses PAP, QBQ, are situated on the axis, EABO; we have now to consider the direction of the ray *e*, which proceeds from the extremity of the object through the middle of the object-glass; for the other rays proceeding from the same point *e*, only contribute to strengthen the effect produced by this ray.

2. The ray, eA, passing through the middle of the glass, PP, is not bent, but passing on in the direction AfM, passes by the extremity, f, of the image, and falls upon the eye-glass at M. Here it is necessary to observe, that if the eye-glass is not large enough to reach M, this ray would not enter the eye, and the point, e, would be invisible, that is, in other words, the extremity, e, must be placed near the axis, to make the ray, AfM, fall upon the eye-glass.

3. This ray, AM, will be refracted by the eye-glass; the mode of its refraction will be easily inves tigated; to this end let us consider the second image Gg. Now the line, Bf, prolonged, falls upon g, the

extremity of the second image, and the refracted ray takes the direction NO, which being prolonged falls upon g.

4. Since then the two lines, ON and Bf meet at g at an infinite distance, they may be considered as parallel to each other; therefore, to determine the position of the refracted ray NO, we have only to draw a line parallel to the line Bf.

5. From hence it is evident, that the ray, NO, must meet with the axis of the telescope as at O; and since generally when the magnifying power is great, the point, F, is much nearer the glass, QQ, than the glass PP, the interval, BM, will be a little larger than the image, Ff; and as the line, NO, is parallel to fB, the line, BO, will be almost equal to BF, the focal distance of the eye-glass.

6. The eye being placed at O, will receive not only the rays which come from the middle of the object, E, but also those which proceed from the extremity e, and consequently those which come from all other parts of the object; the rays from BO and NO will fall at the same time on the eye, however small the pupil may be: the field, therefore, in this construction does not depend upon the size of the pupil, provided the eye be placed at O, but the moment the eye is removed from O, the apparent field is diminished.

7. If the point, M, was not at the extremity of the eye-glass, it would transmit rays that were further removed from the axis, and the field would be larger. Therefore, to determine the field of which the telescope is capable, draw from A, the middle of the object-glass, to M, the edge of the eye-glass, the line AM; this continued to e, the object will mark the visible extremity thereof, consequently the angle EAe or BAM gives the semidiameter of the apparent field, which is consequently augmented in proportion as the eye-glass is larger. In the first

kind, the field depended on the aperture of the pupil of the eye, in this, it depends on the aperture of the eye-glass.

By the object-glass, the object is carried from Ee to Ff; by the eye-glass, it is as it were removed from Ff to Gg; the image Gg, from being at such a distance, is seen distinctly. This image is seen by the eye at O under the angle G O g or B O N, while the object is seen by the naked eye under the angle E A e; the telescope, therefore, magnifies in the same proportion as the angle, B O N, is greater than the angle E A E. Now, as N O is parallel to B f, the angle B O N is equal to the angle F B f, and the angle E A e is equal to F A f; therefore the magnifying power may be determined by the proportion between the angles F B f and F A f. Now, F B f is as much larger than F A f, as the line A F is larger than the line B f, or as much as the focus of the object-glass exceeds that of the eye-glass.

SUMMARY OF THE PROPERTIES OF THE ASTRONOMICAL TELESCOPE.

1. The magnifying power is in the proportion of the focal distance of the object to the eye-glass.

2. The rays emerging from the eye-glass to the eye should be parallel for a good eye; if this does not suit another eye, then the tube must be pushed in or pulled out till the object appears distinct.

3. The apparent magnitude of an object is the same, wherever the eye be placed, but the visible area is the greatest when the eye is nearly at the focal distance of the eye-glass.

4. The object is always inverted.

5. The visual angle depends on the breadth of the eye-glass; for it is equal to the angle which the eye-glass subtends to the object-glass from E e, *fig.* 16.

There are two other circumstances relative to the perfection of telescopes, which we have now to consider; *viz.* the brightness or quantity of light, and the distinctness with which objects are seen.

With respect to brightness, the telescope may be considered as perfect when it represents them as bright as they are seen by the naked eye, which is the case when the aperture of the pupil is filled by the rays which come from each part of the object after being transmitted through the telescope; so long as a telescope furnishes a sufficient quantity of rays to fill the aperture of the pupil, no greater brightness can be desired, for a greater quantity would be useless. But as the size of the pupil varies, it has been usual in considering this subject, to consider it of about one-tenth of an inch diameter: when you consider that the light of the sun is reckoned to exceed that of the moon 300,000 times, you will easily perceive that a small diminution of light is not of any great consequence. Let us, however, examine the rays transmitted by the telescope, and compare them with the assigned diameter of the pupil; this will be clearer by attending only to one point of the object, that, for instance, which coincides with the axis of the telescope.

1. The object being at an infinite distance, the rays which fall upon the surface of the object may be considered as parallel to each other; therefore all the rays which come from the center of the object will be contained between the lines e P, e P, parallel to the axis EA, *plate* 6, *fig.* 15. All these rays taken together are named the pencil of rays, which fall upon the object-glass; and the thickness of this pencil is equal to the aperture of the object-glass, whose diameter is PAP.

2. This cylindrical pencil of rays is changed into a conical one, P F P, by the object-glass; after

having crossed at the focus F, the rays proceed and form another cone, the apex of which is at the focus, and the base is the eye-glass. Now it is evident, that the base of the cone, m m, is as much smaller than the pencil P P, as the distance, F B, is shorter than the distance A F.

3. Now the rays F M, F M, after passing through the eye-glass, again become parallel to each other, and form the pencil n o, n o, which enter the eye, aud paint thereon the image of that point from which they originally proceeded.

4. Every thing turns now upon the size of the pencil of rays, n o, n o, which enters the eye; if the diameter thereof is equal or greater than the aperture of the pupil, it will be filled, and the object will be seen with all possible brightness.

5. But if the size of this pencil should be much smaller than that of the pupil, it is clear that the representation would be obscure, which is a great defect in any telescope; to prevent which, the last pencil of rays should be rather more than $\frac{1}{20}$th of an inch in diameter, though it would be better if it was nearly $\frac{1}{10}$th of an inch.

6. Now it is evident, that the size of the last pencil of rays depends on the size of the first by which it is formed, which is easily determined; for we have only to see how much smaller n n is than P P, the aperture of the object-glass. Now, P P is to n n as A F to B F, on which the magnifying power depends; therefore the magnifying power shews how much larger the pencil E P, E P, is than the pencil n o, n o.

7. from hence it is evident, that the aperture of the object-glass should be increased in proportion as the magnifying power is augmented; consequently, if this proportional diameter cannot be given to the object-glass, the telescope will be defective.

Opticians have established, as a general rule, that the aperture of a lens should always be smaller than half its focal distance.

Distinctness of expression is confessedly the most important article in the nature of telescopes; and to attain it, has exercised the genius, and called forth the abilities of a *Newton*, *Dollond*, *Euler*, *D'Alembert*, &c.

You may remember that I assumed as a principle, that a convex lens united in one point the image of all the rays proceeding from any given point of an object. If this were rigorously true, the images formed by lenses would be as well terminated, and as perfectly defined, as the object itself.

But this principle is only true to a certain degree, and with respect to those rays that are near the center of the lens; for the rays which pass through the glass at a distance from this center are not collected in the same point with those which pass through the middle, and from this double image great indistinctness arises.

To render this more clear, we must again have reference to a diagram. Let P P, *plate* 7, *fig.* 7, be a convex glass; E e, an object situated on the axis thereof; E, the point coinciding with the axis, and sending out rays E M, E N, E A, E M, E N, on the surface of the glass. We have to consider how the direction of these rays is changed by the lens.

1. The ray, E A, passing through the middle of the glass, is not refracted, but proceeds in the same rectilinear direction A B F.

2. The rays, E M, E M, which are very near to E A, are only refracted in a small degree, but so as to unite somewhere, as at F, which point of union we have considered as the focus of the lens.

3. The rays, E N, E N, which are further from the axis, or nearer the edge of the glass, are refracted

somewhat differently, so as to meet at G, nearer the lens than the point F, forming a separate image G g.

4. This circumstance, concerning the rays which fall upon the lens at a distance from the center, and there forming another image of the same point, separate from that which is formed by the rays that pass nearer the center of the lens, though I have not noticed it to you before, merits considerable attention.

5. From hence you will perceive, that the first image, F f, is formed only by the union of those rays which are very near the middle of the glass, and that a succession of images is formed by the rays that are more and more removed from the axis, till at last you come to those which fall near the edge of the lens, which form the image G g.

6. An indefinite number of images are therefore formed between F f and G g, by the rays that fall upon the surface of the lens between the axis and the edge thereof.

7. This succession of images is termed the aberration arising from the sphericity of the glass, or the diffusion of the image; and it must be evident to you, that when these rays enter the eye, the vision obtained thereby of the original point must be confused and indistinct; but if the space, F G, could be reduced to the point F, there would be no confusion or want of distinctness.

8. This diffusion or dispersion of the rays is greater in proportion as the arcs, PAB, P B P, are larger segments of their respective circles; and you will perceive from thence, that very thick and convex lenses are to be rejected; thus, in this figure, where the arcs, PA P and P B P, are the fourth part of the whole circumference, the confusion would be insupportable.

9. Some authors who have written upon this subject observe, that the arc forming the lens should not contain more than twenty degrees of its respective circumference.

10. But if the lens be designed for the object-glass of a telescope, it must be formed of an arc containing fewer degrees; for though the dispersion of the rays may be insensible in itself, the magnifying power multiplies it as often as the object itself: hence, the greater the magnifying power, the smaller the number of degrees that should be embraced by the object-glass.

When the dispersion of the rays is very great, it may be lessened by covering the edge of the lens with an opake ring, leaving only a small aperture round the center of the lens; by this means distinctness is restored, but brightness is diminished, and as much is lost on one hand as is gained on the other; the more so as every increase in magnifying power requires a proportional increase of aperture. Opticians have therefore, with much pains and assiduity, endeavoured to discover some means of correcting this dispersion, without lessening the aperture of the object-glass.

The focus of the rays which pass through the middle of a convex lens, is, as you have seen, further from the lens than the focus of the rays which pass near the edge of the glass. Now, it has been observed by opticians, that a concave lens produces a contrary effect; they have, consequently, investigated this subject, in order to see whether they could not combine a concave with a convex lens, so as to correct or destroy this aberration, while the compound lens produced the ordinary effect of a simple object-glass. We have already shewn you, that concave lenses are considered according to their foci, as well as convex lenses, but with this diffe-

rence, that the focus of a concave lens is virtual or imaginary, and falls before the lens, while that of the convex is real, and falls behind the lens. These circumstances being considered, opticians reasoned in the following manner:

1. If you place a concave lens behind a convex one of the same focal distance, the rays that would have been united in its focus are so refracted as to be rendered parallel to each other, as they were before they entered the glass.

2. In this case the concave lens destroys the effect of the convex, and the rays go on in their original and natural order.

3. If the focal distance of the concave lens is smaller than that of the convex, the effect would be greater, and the rays rendered diverging. Thus the incident parallel rays, L M, L A, L M, *plate* 7, *fig.* 8, passing through the glasses, P P, Q Q, will go on diverging in the direction N O, B F, N O. These two glasses therefore, when combined, produce the same effect as a single concave, that would give to parallel rays the same degree of divergence. Two glasses combined together, of which the concave has a smaller focal distance than the convex, are equivalent to a single concave glass.

4. But if the concave lens Q Q, *plate* 7, *fig.* 9, has a longer focal distance than the convex lens P P, it will not even render the rays parallel that the convex lens would unite at its focus F; but it will, however, so far lessen their convergence, that instead of meeting at F, they will unite at O, a point further from the lens.

5. The combined lenses in this instance produce the same effect as a single convex lens, whose focus would be at O. It is evident then, that it is possible to vary infinitely the combination of two lenses, the one convex and the other concave, so that the

combined lenses may be equivalent to any given convex lens.

6. Such a combined lens may be applied to a telescope instead of a single lens, and the effect with respect to magnifying power will be still the same; but the degree of diffusion or dispersion in the rays will be very different; it may be greater or much less than in a single lens: in the last case the double object glass will be far preferable to a single one.

7. But what is still more advantageous, it is possible so to arrange them, that this dispersion may be destroyed. Calculation discovers these combinations, but the hand of the artist is not perfectly equal to the execution.

The combination of two lenses in the manner that I have here described, forms what is called a compound object-glass; the end to be attained is, that the rays which pass through the lens, as well those at the edge as those at the center, may be united in a single point, and form only one image, without such a dispersion of the rays as takes place in a single object-glass.

Many are the advantages that would be derived from such a combination; the object would appear more distinct and better terminated, because the vision would not be confused by that mixed succession of images produced by a single object-glass. This dispersion of the rays is one of the principal reasons which forces us to make use of very long telescopes, in order thereby to diminish the effect of the dispersion; but if this dispersion was entirely destroyed, much smaller ones might be used, that should be productive of the same effect.

It will be necessary to observe to you here, that the sides or faces of the lenses may be formed in different ways, almost *ad infinitum*, and yet the foci

remain the same; this is effected by forming the sides of equal or unequal radii, as will be evident by considering an example. Let us suppose that a convex lens, whose sides have been formed on a tool of twenty-four inches radius, consequently each face is the segment of a circle of twenty-four inches radius; it will be equally convex on both sides, and be of twenty-four inches focus, as commonly estimated; but as the focus depends on the refraction, it varies according to the density of the glass; generally the focal point is nearer the lens than the radii of the face, sometimes a tenth or twelfth part, so that the lens that we have supposed to be ground on a tool of twenty-four inches radius will have its focus at twenty-two inches.

By making the surfaces unequal, an infinite variety of lenses may be formed, that shall all have the same focus; *ex. gr.* if one face be taken of a smaller radius than twenty-four inches, the other must be taken of a longer, the one thus compensating for the other. The following table exhibits a view of some of the varieties with which the two faces of a lens may be worked, and yet produce the same effect.

Glasses.	Radius of 1st face.	Radius of 2d face.
1	24	24
2	21	28
3	20	30
4	18	36
5	16	48
6	15	60
7	14	84
8	13	156
9	12	infinite.

In the last or ninth form the radius is only twelve, the half of twenty-four inches; but the other face,

the segment of a circle, whose radius is infinite, and therefore may be considered as a straight line; and therefore this lens would be a plano-convex.

If you are desirous that one of the faces be formed of a smaller radius than twelve inches, the other face must be concave, and the glass will be convexo-concave, or what is termed a meniscus. The following table is a specimen of figures for this form:

Meniscus.	Radius of 1st face.	Radius of concave.
10	11	132
11	10	60
12	9	36
13	8	24
14	6	12
15	4	6
16	3	4

You have here then sixteen different kinds of lenses, whose foci will all be at the same distance or point. If the focus only were considered, it would be indifferent which of these were employed; yet it is not so with respect to the dispersion of the rays, for in this respect they differ considerably; it is much more in some than in others. Amongst these, that of the seventh kind is one of those where the dispersion is least, being nearly one half less than it would be if the lens were equally convex on both sides; and it is therefore an advantageous figure for a single object-glass.

From what has been said, you perceive, that in order to correct the aberration that arises from the sphericity, it is necessary to resolve a problem which will discover what are the proper radii for the two surfaces of a lens, so that the dispersion of the rays may be annihilated; the solution requires a considerable knowledge of the more profound parts of

geometry, and therefore does not come within the compass of these Lectures; enough, however, has I hope been said to render the subject clear to you, and to point out the necessity and nature of these investigations.

There is still another aberration to be corrected, another cause of dispersion in the rays to be counteracted or destroyed; this seems more important and more difficult to be cured, as it does not depend on the glass, but on the nature and properties of the rays of light. You no doubt remember what I have already told you respecting the variety in the rays, according to the different colours they occasioned, that is, that they were of different degrees of refrangibility; thus, that the red-making rays were the least refracted, and the violet-making rays the most refracted, all the other rays falling within these two extremes.

Thus when a beam of light falls obliquely upon a piece of glass A B C D, *plate* 7, *fig*. 10, instead of proceeding in the same direction P Q, it is not only refracted but separated into several rays P v, P t, P s, P r, of which the first P v, that is the least refracted, represents the red-making ray, and the last P r, the violet-making ray. Their divergence is indeed much less than that which is represented in this diagram, but sufficient to become sensible.

From this difference in the refrangibility of the rays, arise various phenomena with respect to dioptric glasses, among which are the following:

1. Let P P, *plate* 7, *fig*. 11, be a convex lens at a considerable distance A O, from the object O o, to determine the image formed by the lens, without taking into consideration the aberration already discussed; or, what comes to the same thing, only considering the rays that pass through the middle of the lens.

2. Let us suppose that the object, O o, be red, and the rays proceeding therefrom will be all red-making rays, and will form somewhere a red image, R r, of the object, and R will be the focus of the red-making rays, or those which have the least refraction.

3. But if the object, O o, be violet, the rays will be more refracted, and the image, V v, will be nearer the lens, and the point, V, will be the focus of these rays.

4. If the object be of any of the intermediate colours between these two, the image will fall between R and V.

5. But if the object is not of an homogeneous colour, or is white, as is the case in most bodies, the different kinds of rays are separated by refraction, and each kind forms an image apart; that formed by the red-making rays will be found at R r, and that by the violet at V v, and the space, R V, will be filled by images of the intermediate colours.

6. The glass, P P, will represent an indefinite number of images of each object, O o, formed in the space V R, and situated in the order of the prismatic colours.

7. Each of these images will be distinct in itself, but taken together productive of a very sensible confusion.

8. Here then is another species of dispersion totally independent of that which we have already treated of, and tinging each image with a particular colour.

9. This dispersion depends considerably on the focal distance of the lens, being about $\frac{1}{28}$th part; when the focal distance is twenty-eight feet, the space, V R, is about one foot. If the lens was of fifty-six feet focus, V R would be about two feet.

I have now explained to you a second source or cause of indistinct or imperfect vision; namely, that which arises from the different refrangibility of the rays: which requires a different mode of correction from the former error, which I shall treat of when we come to speak of achromatic telescopes; and only shew here, how the error may be in a degree corrected by the disposition of the eye-glasses.

1. It is certain, that the object-glass forms an infinity of images of each object, successively ranged in the space of diffusion, each of which is tinged with its proper colour.

2. Each of these images becomes an object, with respect to the eye-glass, with its respective colours; and if, instead of one eye-glass, more are used, the same thing still takes place.

3. Let us therefore, in this diagram, *fig*. 11, consider the last images that the telescope forms for the eye at O, and let R r be the red image, and V v the violet; the other colours falling within this space, according to their different degrees of refrangibility. The lenses are not exhibited in the figure, because we are only to consider the manner in which the images are seen by the eye, supposing the distance from the eye to them to be very great.

4. All these images, together with the intermediate ones, are situated on the axis, O B V, of the telescope, and terminated by a straight line r v, that we may call the terminator of all the images.

5. According to the representation in the figure, the red image, R r, is seen by the eye at O, under the angle R O r, which is larger than the angle V O v, under which the violet image, V v, is viewed; the violet rays, which enter the eye, are therefore mixed with the red rays which proceed from the part, R r, of the image R r; and, conse-

quently, there is a very great confusion of the images.

6. But the ray, O r, not being mixed with the others, the extremity or edge of the image will be red; but will soon after be mixed with the other colours, forming the iris, which is so common in other telescopes. If the largest image was the violet, the confusion would be as great as before, with only this difference, that the extreme edge would be violet, not red.

7. Much of the confusion will depend, therefore, on the position of the terminator r v; and from the various situations that may be given to it, this confusion will be sometimes greater, and sometimes less.

8. Suppose that the images were so arranged, that the terminator, v r, passed directly into the eye by a single ray r v O; then the extremities of the image, and all the points which answer to one point in the object, would form only one point in the eye, and the point of the object would be represented distinctly.

9. This advantage is to be obtained when the terminator, being prolonged, passes directly into the eye; and such a position is to be sought for in the arrangement of the eye-glasses.

Before we enter upon achromatic telescopes, I shall endeavour to explain the nature of telescopes with three eye-glasses, in which the image is seen erect.

1. Let the four glasses A, B, C, D, *plate* 8, *fig.* 7, in the tube represent the telescope; the glass, A, directed towards the object, is called, as we have before said, the object-glass, the three others the eye-glasses: the four glasses are convex.

2. Let us consider the effect produced by each eye-glass, the object, o O, being supposed at a con-

siderable distance. The object-glass will form an image of the object at P p, its focus; the size of this image may be found from o, through the middle of the glass A. I have not drawn this line, in order to avoid confusion from a multiplicity thereof.

3. The image, P p, now becomes an object, with respect to the eye-glass B, which is so placed, that the interval, B p, is equal to the focus of B; by this the second image is transported to Q q, and is inverted, as well as the first P p; its size is determined by a line drawn from the middle of the glass B, through p.

4. The interval, A B, between these two lenses, is equal to the sum of their foci, forming the astronomical telescope already explained; the image being inverted, and magnified as many times as A P exceeds B P; but, instead of the eye-glass, another lens, C, is placed behind B; with respect to this lens, the image, Q q, becomes the object, which being at a considerable distance, the lens, C, forms an image thereof at its focus, r.

5. The image, Q q, being inverted, that of R r will be inverted, as to the image, and terminated by a right line drawn from q, through the middle of the glass C, which will pass by r; consequently, the three lenses A, B, C, give the image of the object, O o, at r, and this image is upright.

6. You have now only to place the third lens so that the interval, D R, be equal to the focus. By this the image will be again, as it were, transferred to an infinite distance S s, of which the size will be determined by a straight line drawn through the middle of the glass D, and passing by the extremity of the image r, and the image, S s, will be seen by the eye, instead of the object O o.

7. It is easy now to determine how many times a four-glassed telescope magnifies the object. For

this purpose, you have only to consider the lenses in pairs, A, B, and C, D; each of these, taken separately, being an astronomical telescope. The first pair of glasses, A and B, magnify the object as many times as the focal distance of A exceeds that of B, and just so many times the image, Q q, exceeds the object O o.

8. Q q being now considered as the object, is magnified as many times as the focus of C exceeds that of D; these two powers, added together, give the total manifying power of the telescope.

Plate 4, *fig.* 11, is a perspective view of a model designed to illustrate more clearly the nature of a four-glass telescope, which shews the objects in their true positions; the rays of light are represented by silken strings of different colours, so that their progress is easily traced; A B C the object, D E the object-glass, I K, M N, Q R, the eye-glasses, so placed that the foci of D E and I K meet in G. Those of I K and M N may meet at L, and those of M N, Q R, may meet in g. From the progress of the rays, you perceive that the image at H T is inverted, that the rays proceed from I K in a parallel direction, crossing at L, from whence they go on to M N, pass through it, and are thereby converged into a focus, and form a second image, f g n, erect, which image will be viewed by the eye in the focus of the eye-glass Q R. At *plate* 4, *fig.* 12, another model is represented, formed with glass lenses, to try experimentally, in a darkened room, the places of the images.

SUMMARY VIEW OF THE PROPERTIES OF THIS FOUR-GLASS TELESCOPE, *plate* 4, *fig.* 11.

The magnifying power is in proportion as the focal distance of the object-glass is to the focus of one of the three eye-glasses, all being equal.

It shews the object erect, but not so bright as in the telescope with two lenses; because the other eye-glasses reflect a considerable quantity of light which is lost.

The visible area depends on the breadth of the first eye-glass.

The brightness of an object, seen through a given telescope, is greater in proportion as the aperture of the object-glass is greater.

If the aperture and focus of the object-glass remain the same, an object appears brighter or fainter according to the greater or less focal distance of the eye-glass, that is, according to the magnifying power; for the same quantity of light being spread over a greater or smaller surface, renders the image obscure or brighter.

ON THE CONSTRUCTION AND MAGNIFYING POWER OF TELESCOPES MADE WITH SEVERAL EYE-GLASSES.

In this diagram, *plate* 8, *fig.* 1, A is the first, B the second, C the third, D the fourth, E the fifth convex eye-glass, and O the object-glass. OA, the axis of the telescope, is also the common axis of all the lenses; I m w, an oblique pencil passing through the object-glass, and falling on the extreme edge of the lens which is next the object-glass. O w is the axis of the pencil, represented by a black line, shewn as refracted successively into the lines w v, V t, t S, S r, r α, cutting the axis of the telscope, when they are produced, in the points ϵ, δ, γ, β, α, respectively. O is the focus of this oblique pencil after refraction at the object-glass; e, d, c, b, the successive foci of this pencil after refraction at each of the eye-glasses. From each of these foci draw perpendiculars to the axis of the telescope, and these perpendiculars, OX, e g, dh, CZ, by, will be

places and magnitudes of successive images either real or imaginary; real when the image is actually formed, so that it would be visible if the rays were received upon a white paper; imaginary when the rays after refraction proceed as if they came from or tended to such an image, although this image is not actually formed. *When the image is real, the rays of each pencil actually come to a focus.* When it is imaginary, these rays after refraction diverge from or converge towards such a focus, but are never actually united.

Although each lens has its image either real or imaginary, yet there are only two real ones in the construction here delineated, the first, e g, inverted, the second, b y, upright.

When the number of real images is even, the object will be seen upright; when that number is odd, the object is inverted. *Galileo*'s telescope, in which there is no real image, shews the object upright; it cannot, therefore, be applied to instruments in which cross wires are necessary, because the wires cannot be so placed as to be seen distinctly together with the object.

All that is essential to the construction of telescopes is, only that the rays of the same pencil, which enter parallel, should likewise emerge parallel, for the object will in that case be seen distinctly; the intervals and focal lengths therefore of all the lenses except one, may be assumed at pleasure, from whence that one must be determined. This assertion of most writers on optics is true, if nothing else be attended to but the course of a few rays coming from a single point in the axis of the telescope, and it be only required that the middle of the object be seen distinctly; but the case is very different, if it be required that all parts of the object should be seen as far as may be equally distinct, for then the aberration of the extreme pencil in passing through the eye-

glasses must be taken into consideration; and the number, place, and focal lengths of the eye-glasses, must be such as may lessen at least, if not remove these aberrations.

It may be observed, that generally in any single lens, the greater the focal length, and the less the aperture, the less will be the aberration of the refracted rays. That construction is therefore, *cæteris paribus*, the best, in which the eye-glasses have large focal distances and small apertures; those especially that are concerned in forming the last image. As to the single lens, by which the last image is viewed, it may be allowed to have a short focal length, particularly if its aperture may be contracted; for though this lens magnifies the faults already made in the last image by the other glass, it does not create new faults.

Among the various sorts of telescopes made with convex lenses, and designed to shew the object upright, those with four or five glasses are preferable to those with fewer. The fewer lenses there are in the eye-tube, the greater must be the refraction of the extreme pencils at each lens, supposing the sum of all the refractions, or the whole change in the direction of the pencils, to be the same. Now, though the number of refractions is increased, yet if the quantity of each refraction be proportionably diminished, the sum of all the aberrations in these pencils will be greatly lessened; and the loss of light, by passing through more glasses, will be very inconsiderable.

Agreeable to this principle, it is found, that an object seen through two double convex lenses, both of a size, and put close together, appears distincter near the edges of those lenses, than if seen through one lens whose focal length is equal to that of the other two so combined together: likewise two equal plano-convex lenses shews an object distincter at their edges when combined with their convex sides

touching each other, than contrariwise. Thus then the aberrations from the figure of the eye-glasses may be lessened, by increasing the number and diminishing the quantity of the several refractions.

The lens E, *fig.* 1, which intercepts the rays before the first image is formed, diminishes the magnifying power, but improves the distinctness of the telescope, by lessening the diameter of the apertures of the very convex lenses D and C. The extreme pencil O W, which diverges from O, being refracted by this lens into W V, is made to converge towards the axis of the telescope, so that if produced it would meet at ε. By this means the semidiameter of the lens, D, is reduced to D V, whereas if the first real image had been formed at O x, by the object-glass only, the extreme pencil, O o, in that case continuing to diverge, the semidiameter, D V, must have been greater than the image O x, to take in the same field.

The rays belonging to this and every other pencil which diverge from e g, the first real image must be made to converge again by the two lenses D and C, that a second real image may be formed upright. Two lenses are employed for this purpose, because the errors in the second image will be lessened by their contrary refractions; supposing therefore their convexities equal, and that the rays of this pencil, refracted into v t, go parallel or nearly so between the lenses D and C, then it is evident, that the focal length of D must be equal the distance e v (=g D), or nearly so; therefore the lenses D and C, having a shorter focal length, will by no means admit of an aperture, whose semidiameter is greater than o x. It may be further observed, that this pencil, which at first diverged from the axis of the telescope, in the angle w O E and v δ D, by the interposition of the lens E, this change is made at two refractions, at w and v, which must other-

wise have been made by the refraction of the lens D only.

In like manner, the other lens B, which intercepts the rays just before the second real image is formed, diminishes indeed the magnifying power, but makes the telescope more distinct. The extreme pencil we have been considering, after refraction at t, by the lens C, diverges from the axis of the telescope, proceeding as if it came from the point γ; but being refracted by the lens B, into s r, is made to converge, so that if produced it would meet the axis of the telescope in β. This lessens the last image, reducing it from c z into b y; and as it is this image which is viewed by the eye through the eye-glass A, the interposition of the lens, B, lessens the magnifying power, the eye-glass, A, remaining the same. The extreme pencil, S v, thus converging upon the eye-glass A, the semidiameter of this glass will be reduced to A r; whereas, had the lens been not interposed, the extreme pencil, t s e, continuing to diverge from γ, the semidiameter of this eye-glass must have been greater than the image c z, to take in the whole field. As a small aperture of the eye-glass, A, is sufficient to take in the whole field when the pencils thus fall upon it converging, this lens may be allowed to have a shorter focal length, and thus compensate for the loss of magnifying power by the interposition of the lens B, without increasing the aberration of the extreme pencils.

You may prove this experimentally by taking out the second eye-glass, then drawing out the tube to make the telescope distinct again, and you will find the magnifying power increased, the field diminished, and perhaps indistinct near the edges.

It is necessary to observe, that this diagram represents the glasses of a five-glass telescope.

OF ACHROMATIC TELESCOPES.

To render this subject plain and clear, I shall recal to your mind a few of those principles which we have already explained. Thus you know that a ray of light, refracted by passing through mediums of different densities, is at the same time proportionally divided or spread into a number of parts, called homogeneal rays, each being the exciting cause of a different colour; and that these rays after refraction proceed diverging.

That a ray of light passing obliquely from a rarer into a denser medium, is refracted towards the perpendicular; but when it passes from a denser into a rarer medium, it is refracted from the perpendicular.

That when a ray of light is refracted out of air into a given medium, or out of a given medium into the air, the sines of the angles of incidence and refraction are in a constant ratio.

But light consisting of parts which are differently refrangible, each part of an original or compound ray has a ratio peculiar to itself; and that the more the heterogeneous ray is refracted, the more will the colour-making rays diverge, as the sines of the homogeneous rays are constant, and equal refraction produces equal divergences.

From hence you have also been shewn, that the rays, when passing through a convex lens, instead of uniting at one focus, form as many foci of different distances, as there are coloured rays; and that the prismatic colours or irises, which appear towards the borders of convex lenses, render the images confused.

The indistinctness of vision produced by this cause, which is sensible in telescopes of a small aperture, increases into so high a ratio upon enlarging the

aperture, namely, as the cubes of the diameters, that unless this confusion of colours were corrected, it would be impossible to increase greatly the power of refracting telescopes, without extending their length to a very inconvenient size.

It was known before Mr. *Dollond*'s, that different transparent bodies possessed some a greater and some a less refractive power; and it was taken for granted, until he evinced to the contrary, that the dispersive power of the coloured ray was in every transparent body proportional to its mean refractive power; or, in other words, that the refraction of the coloured rays, whatever body they passed through, were always in a constant determinate ratio to each other. Consequently, if the dispersion produced by a convex lens, were counteracted by another lens or medium of a concave form, that the refraction would also be totally destroyed; and that this would be the event, if the two lenses were even made of the same matter. Upon this supposition, it was impossible ever to correct this fault in dioptric telescopes.

While opticians continued to think, that equal refractions would, in every sort of medium, necessarily produce equal divergences, and that, consequently, equal and contrary refractions would destroy each other, and that the divergency of colour from one refraction would be corrected by the other, there could be no possibility of producing any refraction that would not be affected by the different refrangibility of light. For, however a ray of light might be refracted backwards and forwards by different media, provided it was so done that the emerging ray was parallel to the incident one, it would always be white or colourless; but if it came out inclined to the incident ray, it would diverge and be ever after coloured.

This erroneous supposition was countenanced by an experiment of Sir *Isaac Newton*, of placing two prisms, one made of glass contained within a prismatic vessel, filled with water, in such manner that the rays of light which were refracted by the prism of glass should pass through and be refracted in a contrary direction, and in as great a degree by the water prism; by which means he relates, that light thus restored to its original direction was white and free from colours.

In the year 1757, the late Mr. *John Dollond* repeated this famous experiment of *Newton*, of refracting a ray of light through prisms of glass and water, placed with their refracting angles in opposite directions, and so proportioned to each other that the ray after these opposite refractions emerged parallel to the incident ray. According to the Newtonian doctrine, there ought here to have been no divergency of the heterogeneal rays, and no colour produced by these equal and opposite refractions.

But this was not the result of the experiments; the ray was very sensibly coloured. Mr. *Dollond*, finding that opposite refractions produce colour notwithstanding the parallelism of the incident and emergent ray, concluded, that by properly adjusting the angles, he might effect an inclination of the refracted to the incident light, without any colour or divergency. Experiment proved his reasoning to be just.

It may be proper to observe here, that those media are said to have the same mean refractive density, which, under equal obliquities of incidence, equally refract the mean refrangible ray; and two media are said to have the same dispersive power, which produce an equal inclination of rays of the same colour to the mean refrangible ray, when the

whole refraction of the mean refrangible ray is equal in both.

*Let the vertex of a flint-glass prism, the refracting angle of which is equal to 23° 40′, be applied to the base of a crown-glass prism, the refracting angle of which is equal to 25°; a ray of solar light will pass through the prisms when their surfaces are contiguous, but the emergent ray will be coloured.**

The ray is supposed to fall perpendicularly upon the surface of the prism, whose refracting angle is the greatest.

The position of the prisms in this experiment is such, that the effects of refraction upon the parallelism of the homogeneal rays passing through them are contrary to each other, and consequently if they were equal the rays would emerge parallel. But the flint prism, by its greater dissipating power, more than counteracts the separation of the rays caused by their passage through the first prism, which was equal to 38½ minutes; and, inverting the order of the colours, causes the red and violet rays to emerge, inclined to each other at an angle of 12½ minutes, sufficiently great to produce a sensible tinge of the prismatic colours in the emergent rays.

Every thing remaining as in the last experiment, let the vertex of a crown-glass prism, the refracting angle of which is 10°, be applied to the base of the flint prism. If a ray of solar light passes through the three prisms, when their surfaces are contiguous, the emergent ray will deviate about 5° 37′ from the course of the incident ray, but will be colourless.

In this case the two crown-glass prisms refracting the ray in the same direction, cause it to deviate from the course of the incident ray about 5° 37′ more than the deviation in the contrary direction arising from refraction through a flint prism.

* *Atwood*'s Analysis of a Course of Lectures, p. 164, 165.

But the flint prism, by its greater dissipating power, exactly counteracts the separation of the rays caused by refraction through the other two prisms, so that the homogeneal rays emerge at length parallel, and of course colourless.

Now this was what was wanted; for you have seen, that the difficulty which chiefly impeded the improvement of telescopes was, so to refract a ray while it deviated considerably from its original course, that the dispersion of the homogeneal rays might be counteracted, and that by these means they might all emerge parallel, and of course free from colour; and this is, you perceive, effected by a combination of transparent substances, the refracting and dissipating powers of which are different.

In this experiment, the rays of mean refrangibility emerge at an angle of refraction equal to 16° 57′.

If a solar ray impinged upon the surface of the prism last applied at an angle of incidence equal to 16° 57′, the angle of dissipation after emergence into air would be equal to $12\frac{1}{4}$°.

But it was shewn in the former experiment, that the dissipation of the rays emerging from the two prisms was equal to $12\frac{1}{4}$; for which reason, and on account of the contrary position of the prisms, the red and violet rays emerging, inclined to each other at an angle of $12\frac{1}{2}$ from the two prisms, and falling upon the third, will be refracted out of it colourless.

It appears then that two kinds of glass are necessary for achromatic telescopes, one of which shall possess as small, and the other as great dispersive powers, relatively to their mean refractive ray, as can be procured.

The difference of glass in this respect depends on the quality of the ingredients employed in their composition.

Crown-glass, which is composed of sand, melted by means of the ashes of sea-weeds, barilla, or kelp,

both which fluxes are known to consist of vegetable earth, alkali, and neutral salts, is found to give the smallest dispersive power.

Plate-glass, which is composed of sand melted by means of fixed alkali, with little or no vegetable earth, gives a greater dispersive power.

The dispersive power of *flint-glass* is much greater than either of the others, and this consists of sand melted by a mixture of minium and fixed alkali. It is probable, therefore, that minium and other metallic calces give the greatest dispersive power, and that alkalis give more than vegetable, and probably other earths.

Let a crown-glass prism, whose refracting angle is 30°, *be applied contiguous to a prism of flint-glass, whose refracting angle is* 19°; *with the vertices of the prisms in opposite directions, a solar ray being refracted through them will deviate from the course of the incident ray, but will not be separated into the coloured rays.*

Here it appears, that the two prisms operate equally upon the parallelism of the homogeneal rays passing through them, and that as these effects by the position of the prisms tend to correct each other, the homogeneal rays, after being refracted through them, emerge parallel and colourless.

Mr. *Dollond* next considered, that as a ray might be refracted free from colour through a wedge, it might also through a lens. When an image of an object is formed by a convex lens, it appears coloured, owing to the dispersion of the rays by refraction; as, therefore, rays can be refracted without dispersion by prisms, he conceived that it might also be done by a conbination of lenses. And in this he succeeded, by considering that in order to make two spherical glasses that should refract the light in contrary directions, as in the two wedges, one must be concave and the other convex; and as the rays

are to converge to a real focus, the excess of refraction must be in the convex lens, because that makes rays converge, and the concave makes them diverge. Also, as the convex lens is to refract most, it must be made of crown-glass, as appeared from the experiments with the wedges, and the concave lens of white flint-glass. Farther, as the angle of dispersion varies inversely as the focal length, very nearly, from the principles of optics, and the angle of dispersion also varies as the dispersing powers, therefore if the focal lengths be taken inversely as the dispersing powers, found from the two wedges, the angles of dispersion will be equal, and, being in contrary directions, they will correct each other, and the different refrangibility of light will be removed.

Upon this principle, Mr. *Dollond* was enabled to make a combined lens to form an image free from colour, and therefore brought to perfection the refracting telescope, making it represent objects with great distinctness, and in their true colours. Instead of forming the object-glass with one convex lens of crown, and one of flint-glass, two convex lenses of crown are used, and the concave one of flint put between them. This construction of the object-glass tends also to correct the error arising from the spherical form of the lens; for, as the rays at the edge of the convex lens tend to a focus nearer to the lens than those at the middle, the concave lens, which makes the rays at the edge diverge more than those at the middle, will counteract the above effect, and bring the rays at all distances from the center of the lens to a focus more nearly together; and by a proper adjustment of the foci, the diffusion of rays at the focus may be rendered inconsiderable. Telescopes thus constructed are called *achromatic*.

This discovery of Mr. *Dollond* was so extraordinary, and so contrary to the best established princi-

ples, that it was not believed at first by Mr. *Euler*. At length, however, Mr. *Zicher* of Petersburg made experiments similar to those of Mr. *Dollond*, and convinced Mr. *Euler* that it was true. He also shewed, that it is the lead which is used in some compositions of glass, which produces the extraordinary property of augmenting the dispersion of the extreme rays, without sensibly changing the refraction of the mean.

Mr. *Euler*, in a paper read at the Academy of Sciences at Berlin, in 1764, was candid enough to own he did not at first credit the account, and thereby gave to Mr. *Dollond* the credit of the discovery. Notwithstanding this, Mr. *De la Lande* in his Astronomy, and Mr. *Fuss* in his Eulogy on Mr. *Euler*, both ascribe the invention to Mr. *Euler*. Mr. *P. Dollond* has however fully proved, that the discovery must be attributed to Mr. *John Dollond*.*

In the same pamphlet Mr. *Dollond* has shewn the reasons which prevented *Newton* from drawing the same conclusions; that it arose from the kind of glass he made use of; so that his veracity remains unimpeached, and the experiments, when made with the same kind of glass, exactly correspond with those of Sir *Isaac Newton*. In his time the English were not famous for making telescopes, many were imported from Venice. The glass imported from this place was nearly of the same refractive quality as our crown-glass, but of a better colour. It is probable that *Newton*'s prisms were made of that glass, because he mentions the specific gravity of common glass to be to water as 2,58 to 1, which answers nearly to that of crown-glass. Mr. *Dollond* made a prism of a piece of this glass, and trying the expe-

* "Some Account of the Discovery by the late Mr. *John Dollond*, which led to the great improvement of refracting telescopes," by Mr. *P. Dollond*.

riment with it, found it answered very nearly to what *Newton* relates; the difference being only such as may be supposed to arise from the same kind of glass made at different times.*

OF REFLECTING TELESCOPES.

Sir *John Pringle*, in his discourse to the Royal Society on the reflecting telescope, attributes the first thought thereof to *Mersennus*, who proposed to *Descartes* a telescope with specula, many years before *Gregory*'s invention; though indeed in a manner so very unsatisfactory, that *Descartes*, who had given particular attention to the improvement of the teles-

* In the Gentleman's Magazine for 1790, page 890, by a writer signing himself *Veritas*, the invention and first construction of the achromatic object-glass is ascribed to *C. M. Hall*, Esq. who, it is said, from considering the perfectly achromatic structure of the humours of the eye, about 1729, imagined that from various glass substances he might construct an achromatic object-glass. About 1753, after many experiments, he completed several achromatic object-glasses, which were found to be very perfect, and bore large apertures. From a workman of the name of *Bass*, whom Mr. *Hall* occasionally employed, and who worked for the optical shops, Mr. *Hall*'s invention is said to be obtained. But complete and perfect achromatic telescopes were unquestionably first made and delivered to the public by Mr. *Dollond*. The theory now is well known to the skilful optician; and it is to the impurity of the flint glass chiefly that telescopes of large apertures and considerable powers are not generally made. It is much to be regretted, that the interest and indifference of the glass manufacturer, and the excise laws, precludes the opportunity of selecting proper glass. To make a good achromatic object-glass requires no small pains; and, supposing that both the sorts of glass be perfectly pure, and the various curves of the glasses of the proper kind, yet, if they are not well centered and fitted up with skill, the glass will be imperfect, and give an ill-defined image.

The variableness in the refractive power of different sorts of glass compels us also to vary occasionally the curves of the lenses; so that the theory only will never in this instance give a constant theorem for constructing any achromatic object-glass whatsoever.

The word *achromatic* is of Greek derivation, and signifies without colour; as a perfect object-glass of a telescope will shew the object

cope, was so far from approving the proposal, that he endeavoured to convince *Mersennus* of the fallacy.

Gregory was led to the invention by seeking to correct two imperfections of the common telescope; the first was, its too great length, which made it less manageable; the second, the incorrectness of the image. It had been demonstrated, that a pencil of rays could not be collected in a single point by a spherical lens, and also that the image transmitted by such a lens would be in some degree incurvated.

These inconveniences he believed would be obviated by substituting for the object-glass a metallic speculum of a parabolic figure, to receive the image, and to reflect it towards a small speculum of the same metal; this again was to return the image to an eye-glass placed behind the great spe-

colourless, this term has been applied to the compound object-glass as first made by the late Mr. *John Dollond*.

The imperfections of glass, as has been observed, is the prevention of object-glasses of large apertures. To obviate this, Dr. *Blair* some years ago made a variety of experiments, by introducing fluid mediums between the two crown-glass double convex lenses, as a substitute for the solid white flint one. He found various mixtures to answer very well, but particularly a mixture of solutions of ammoniacal and mercurial salts. A telescope of his with an object-glass of seventeen inches focal distance and three inches and an half aperture, is said to exceed one of *Dollond*'s of forty-two inches focal length.

As the Doctor conceives that he has thus removed the aberration, he distinguishes his instrument by the term *Aplanatic*. But, upon the whole, it has been remarked that solid object-glasses are yet to be desired; for compounds of fluids are subject in the making to many practical difficulties, and from unavoidable inconveniences to those using them, are prevented from being useful, but only in the hands of skilful philosophers and opticians. It is now some years since the Doctor obtained a patent for the contrivance, and no professed observation or publication of effects by them appear to have been made. The theory of his contrivance the reader will see in the Transactions of the Royal Society, Edinburg, vol. ii.

For descriptions and representations of the best mounted achromatic refractors and reflectors, see my Appendix to this Lecture.

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culum, which for that purpose was to be perforated in its center.

But as *Gregory* was endowed with no mechanical dexterity, nor could find any workman capable of realizing his invention, after some fruitless attempts he gave up the pursuit. And, probably, had not some new discoveries been made in light and colours, a reflecting telescope would never more have been thought of, considering the difficulty of the execution, and the small advantages that could accrue from it, deducible from the principles of optics that were then known.

But *Newton*, whose happy genius for experimental knowledge was equal to that for geometry, and who to these talents, in a supreme degree, joined patience and mechanical abilities, happily interposed and saved this noble invention from well nigh perishing in its infant state.

While he was employed in endeavouring to grind lenses of the figure of one of the conic sections, he happened to examine the colours formed by a prism, and having by means of that simple instrument made the ever memorable discovery of the different refrangibility of the rays of light, he then perceived that the errors of the telescopes, arising from that circumstance alone, were some hundred times greater than such as were occasioned by the spherical figure of lenses. This forced *Newton* as it were to fall into *Gregory*'s track, and to turn his thoughts to reflectors. If *Newton* was not the first inventor of the reflecting telescope, he was the main and effectual inventor.

It was towards the end of 1668, or the beginning of the following year, that *Newton*, being thus obliged to have recourse to reflectors, and not relying on any artificer for making his specula, set about the work himself, and early in the year 1673 completed two small reflecting telescopes; one of these he

presented to the Royal Society, communicating at the same time a full and satisfactory account of its construction and performance, and received from them such thanks as were due for so curious and valuable a present.

But how excellent soever the contrivance was, how well soever supported and announced to the public, yet, whether it was that the artists were deterred by the difficulty and labour of the work, or that the discoveries even of a *Newton* were not to be exempted from the general fatality attending great and useful inventions—the making a slow and vexatious progress to the authors; the fact is, that, excepting an unsuccessful attempt which the Royal Society made by employing an artificer to imitate the Newtonian construction, and a disguised Gregorian telescope, set up by *Cassegrain* abroad, as a rival to *Newton*'s, and that in theory only, for it was never put in execution by the author, no reflector was heard of for near half a century after. But when that period was elapsed, a reflecting telescope was produced to the world of the Newtonian construction, which the venerable author, ere yet he had finished his much-distinguished course, had the satisfaction to find executed in such a manner, as to leave no room to fear that the invention would longer continue in obscurity.

This memorable event was owing to the dexterity, the genius, and application of Mr. *Hadley*, the inventor of the reflecting quadrant, another most valuable instrument. The two telescopes which *Newton* had made, were but six inches long, and in power were compared to a six feet refractor. *Hadley*'s telescope was about six feet long, and equalled in performance the famous aerial telescope of *Huygens*, of 123 feet in length.*

* Sir *John Pringle*'s Discourses, p. 206, &c.

It may be worth observing, that Sir *Isaac Newton* sent his telescope to the Royal Society while his election into the society was depending, and he concludes with saying, "that if he should be elected, he would endeavour to testify his gratitude by communicating what his poor and solitary endeavours could effect, towards promoting their philosophical design." Such was the modesty of the man who was the glory of the society, of the nation, of the world.*

OF THE GREGORIAN REFLECTING TELESCOPE.

The Gregorian reflector consists of two concave mirrors, and two plano-convex lenses for the eye-glasses.

T T T T, *plate* 8, *fig*. 2, is a cylindrical tube; at the bottom of this a concave metallic reflector or mirror, D U V F, is placed: this reflector has a hole in the middle.

Towards the other end a small concave mirror, L, is placed; this is supported on an arm, M, which may be moved nearer to, or farther from the great speculum, at pleasure.

These two mirrors are placed parallel to each other; the small one is generally somewhat larger than the hole in the great mirror. At the bottom of

* After *Newton*, Mr. *James Short*, about the year 1734, constructed reflectors with the metals of the parabolic figure, superior to any other. His telescopes that I have occasionally examined, shew great perfection, but with a copper-kind of colour, arising from the composition of the materials of the metal. From a principle unknown to a liberal philosopher, Mr. *Short* would not disclose the particular progresses by which he figured his metals; and at the time of his death they were supposed to die with him.

Mr. *John Mudge*, after *Short*, made a reflecting telescope, it is said, of equal perfection. The late Rev. Mr. *Edwards* improved very much the reflectors, particularly in the composition of the speculums. From the variety of trials of different ingredients com-

the cylindrical tube, and just opposite the perforation in the large mirror, is a small brass tube, $\alpha\beta\delta\varepsilon$, containing the two eye-glasses; at the further end of this tube is a very small hole, to which the eye is to be applied.

The construction being understood, we may proceed to explain the optical effect of this instrument.

1. The open end of the cylindrical tube being set directly towards the object, which being supposed to be distant, the rays proceeding therefrom may be considered as parallel to each other; and being reflected back by the large concave speculum, they will form an image of the object at its focus, which, from the figure, is evident will be inverted.

Let C represent all the rays proceeding from the point, B, of the object, and E the pencil of rays proceeding from the point A.

The rays, C, falling parallel upon the great mirror, will be thence reflected, and converge in the direction D G; and by crossing at I, the principal focus of the mirror, they will form the upper extremity of the inverted image I K, similar to the lower extremity, B, of the object AB.

In like manner, the rays, E, which come from the top of the object, and fall upon the great mirror at F, are thence reflected converging to its focus, where they form the lower extremity, K, of the in-

pounded by him, have two or three preparations been determined that produce speculums of a fine white and clear colour: it is chiefly from his directions that speculums are now made of a good clear colour.

The largest reflectors ever constructed are those by Dr. *Herschel*; he has fabricated them of the lengths from 18 to 20 feet, upon the constructions of *Newton*, or, peculiar to himself, with one large metal and one eye-tube only. He has lately constructed one of the stupendous length of 40 feet, and its speculum four feet in diameter; for the figure and description of which I refer the reader to the Philosophical Transactions for 1795. EDIT.

verted image, I K, similar to the upper extremity, A, of the object AB.

The rays from these two pencils pass on from I and K to the small mirror, L, the rays from F falling upon it at h; those from D falling upon it at g; from which points they are again reflected.

2. The focus of the small speculum is at n, a little beyond the place where the image is formed by the great speculum.

If the focus of this mirror fell precisely on m, where the image from the other is formed, the rays would be reflected parallel therefrom; but as it is somewhat beyond or longer than that distance, they are reflected converging in the direction g N.

3. The converging pencil of rays, g N, proceeding from the point, g, and reflected by the small mirror, would coincide beyond the telescope if they were not refracted by the eye-glasses. It is the same with the other converging pencil.

But to render the instrument shorter, these converging rays are made to fall on the lens, R, in the eye-tube, which increases their convergence, and makes them coincide at a and b, where they form an erect image of the object at a b. This image being at the focus of the lens S, the rays proceeding from the image formed there are so refracted by it, as to emerge parallel to the eye, and thus produce distinct vision.

The light which falls upon the surface of the large mirror is reflected to the small mirror; the eye therefore receives from the telescope a quantity of light, which is to that which it would receive by naked vision, nearly in the same proportion that the surface of the large mirror is to the surface of the small hole at e, near the pupil of the eye.

The rays passing on from the image, pass through the second eye-glass, S; and through a small hole, e,

enter the eye, f, which sees the image, a b; and, by means of the eye-glass under the large angle, c e d, the second glass, R, increases the field, and renders the image more perfect.

In order to suit different eyes and distances, there is a small rod with a screw at one end; this screw goes through the arm which is fixed to the small reflector, so that by turning the end it brings it nearer, or removes it further from the larger speculum.

An eye-stop is placed at the last image, to cút off the superfluous rays; a very small hole is made at e, to let the rays pass to the eye.

To see near objects, or to accommodate the telescope for long-sighted people, the small mirror must be moved further from the large mirror than when used for distant objects or a common sight; for if an object comes nearer, the image of i at m will come nearer n, and as n m decreases, n P will increase, and will come nearer the lens, R; to reduce or bring it back, the mirror must be removed further.

For short-sighted people, the focus, P, must be brought nearer R, to make the rays more divergent; that is, n P must be longer, and consequently n m shorter, or h g brought nearer to D U, V F.

Therefore, for distant objects, and short-sighted people, turn the screw to the right; but for near objects and old eyes, turn to the left.

This telescope, as you have seen, shews the object erect, but not so bright as in refracting telescopes, because glass transmits more light than metal reflects. It has been estimated, that one third of the light received is lost by reflexion.

The visible area of an object is as the breadth of the eye-glass; for, if the image at I K, and the eye-glass be increased, the image at m will also be increased, because the angles of incidence and re-

flexion at h g are equal, and consequently the visible part of the object is increased.

The brightness of the object is in proportion to the aperture; for the larger this is, the greater is the quantity of light that comes to the eye.

The extreme parts of the image are less bright than the rest, because the shadow of the small speculum falls on the outside; but towards the middle, it only covers the hole.

To render the determination of the magnifying power more easy, I shall consider the tube to be twelve inches long, and two inches diameter; the concave speculum, at the bottom of the tube, to be of seven inches focus, and two inches diameter; the hole in the center $\frac{6}{12}$ of an inch in diameter; the focus of the small mirror $\frac{18}{12}$, its diameter $\frac{8}{12}$ of an inch: the first eye-glass about three inches focus, the second about $\frac{10}{12}$. We must now refer back to our former instructions on the principles of rays of light, when reflected from a spherical concave mirror.

You will recollect, 1st. That the light, which comes from a very distant object, is so reflected, that the point where they meet, and where the image is formed, is $\frac{1}{4}$th part of the diameter of the sphere, of which the great speculum is a segment. 2d. That if the object is at the focus of a concave spherical mirror, the rays falling therefrom are reflected parallel to each other.

Now, distant objects seen through the reflecting telescope, form an inverted image at I K, the focal point of the large speculum, and nine inches therefrom, and the image and object both appear under the same angle from the vertex of the mirror; this image at the focus, I K, being the base of two angles, whose summits are the centers of two spherical mirrors. Now, the distance of the focus of the two mirrors is as $1\frac{1}{2}$ to 9, or as 3 to 18, by taking away

the fraction; or as 1 to 6, by dividing the terms by 3: therefore the two angles are in the proportion of 1 to 6; that is, the angle subtended by the spherical surface, of which AB is a portion, is six times larger than what the object subtends at the surface of the large mirror; consequently, if the eye was placed in the parallel rays proceeding from the small speculum, it would see the object perfectly therein, and magnified in the proportion of the focal distances of the two metals, that is, as 6 to 1.

Now, the two lenses in the eye-tube form a telescope whose property, on the principles already laid down, is to magnify the object in the proportion that the focus of the lens, S, exceeds that of R, in this instance, as 36 to 10; but the telescope was before shewn to magnify in the proportion of 6 to 1. By combining these proportions, we shall obtain 10×1, and 36×6, or 10 to 216, or nearly as 1 to 22.*

OF THE NEWTONIAN TELESCOPE.

The telescope of *Newton* differs a little in the construction from that of *Gregory*, but it is founded upon the same principles, as well geometrical as physical.

* *Fig.* 11 represents the form of the Cassegrain reflector; the only difference between which and the Gregorian is, that the small speculum, G, in this is convex, and in *Gregory*'s, concave, see *fig.* 2; it is, therefore, a variation of *Gregory*'s, and not a new invention, as *Cassegrain* published it to be. This telescope has one or two advantages over others: a shorter tube will admit of equal power with a longer one of the Gregorian; the larger speculum being concave and the smaller one convex, the whole aberration is the difference of the two, and they tend to correct each other. The principal disadvantage is, that it is useful only for celestial objects, as the image is only once formed, and is therefore seen inverted, as *e f*.

When a telescope is wanted both for terrestrial and celestial purposes, the Gregorian is the one to be preferred, and is now universally adopted. It shews all objects in their natural positions, and is of a form the most convenient for portability and readiness in management. EDIT.

It consists, like the former, of a tube to receive the metals; the upper end of the tube is open; at the bottom of this is placed a concave metal reflector, and a plane small metal reflector, inclined 45 degrees to the axis of the large reflector. This small reflector must be of an oval form; the length of the oval should be to the breadth as 2 to 1, on account of the obliquity of its position; it is supported on an arm fixed to the side of the tube; an eye-glass is placed in a small tube, moveable in the larger tube, so as to be perpendicular to the axis of the large reflector, the perpendicular line passing through the center of the small mirror. The small mirror is to be situated between the large mirror and its focus, that its distance from this focal point may be equal to the distance from the center of the mirror to the focus of the eye-glass.

The tube vxzy, *plate* 8, *fig.* 3, being turned with its open end towards the object, parallel rays coming therefrom will be reflected by the concave mirror to its focus, where it would form an inverted image of the object, but from the interposition of the small reflector, fg, they are prevented coming to the focus, and are reflected to t, the focus of the eye-glass, where they form an image equal to what would have been formed at the focus of the concave mirror. This image being in the focus of the eye-glass, the rays proceeding therefrom will be so refracted by the lens, as to emerge parallel to the eye, and therefore properly constituted to produce distinct vision.

If the face be turned towards the open end of the tube, and the eye be applied at h, the object will appear inverted; but if the face be turned towards c d, the object will be erect: the latter position is in most cases very inconvenient.

The magnifying power is in the same proportion as the focal distance of the concave speculum ex-

ceeds that of the eye-glass. This telescope will bear a greater aperture than the Gregorian reflector; less light is also lost from the oval plane than from a spherical reflector. It is by means of a Newtonian telescope chiefly that Dr. *Herschel** has added so many valuable discoveries to astronomy.

The disadvantages under which reflecting telescopes labour, arise from their requiring larger apertures to transmit the same quantity of light; from being more affected by the imperfections of the atmosphere than a refracting telescope; from being liable to tarnish; but principally from the imperfections of the workmanship of the object-speculum, which injures them more than equal faults in the object-glass of refractors.

* This indefatigable astronomer has demonstrated the great use that large reflectors may be of in the observatory. The largeness of their apertures, and the brightness of an object observed will admit of powers to the amount of many thousands of times being applied to them. But such extreme powers are but in very few instances useful; the great advantage by these large apertures is light, and the generality of observations made by the Doctor has never exceeded a few hundreds of times. The requisite machinery to ths reflectors of 12 feet in length, and more, causes them to be very bulky, and suitable only to spacious premises out of doors on the ground purposely appropriated. For a proper idea of his largest telescope, I must again refer the reader to the Philosophical Transactions for 1795. In his largest telescopes, he uses but one simple unperforated speculum, as *a b*, *fig.* 3, and applies an eye-tube with glasses to the inner circumference at the object end, *z*, whereby he views the object to be observed. This method was also used by *Jacques le Maire* so long ago as in 1728, and a figure of the instrument may be seen in the *Machinés approvées par l'Acad.* Tom. vi. pag. 61.

For an improvement in producing the vertical motions to large reflectors, see my Appendix to this Lecture. EDIT.

LECTURE XXIII.

OF MICROSCOPES.

By a microscope we understand an instrument for viewing small objects, rendering those visible which would be otherwise imperceptible. Microscopes are divided into three kinds, *single*, *compound*, and *solar*; single microscopes are those which consist of one lens; compound, those which are formed of two or more lenses; solar, those which are used in a dark room, the object being illuminated by the sun, and the image received on a screen.*

It is generally supposed, that microscopes were invented about the year 1580, a period fruitful in discoveries, when the mind began to emancipate itself from those errors and prejudices by which it had been too long enslaved, to assert its rights, extend its powers, and follow the paths which lead to truth. The honour of the invention is claimed by the Italians and the Dutch; the name of the inventor, however, is lost; probably the discovery did not at first appear sufficiently important, to engage the attention of those men, who, by their reputation in science, were able to establish an opinion of its merit with the rest of the world, and hand down the name of the inventor to succeeding ages. Men of great literary abilities are apt to despise the first dawnings of invention, not considering that all real knowledge is progressive, and that what they deem trifling may be the first and necessary link to a new branch of science.

* For figures of all the various improved microscopes, see our Author's Essays on the Microscope, a new edition, just published, with many corrections and considerable additions, by *Frederick Kanmacher*, F.L.S. EDIT.

The microscope extends the boundaries of the organs of vision; enables us to examine the structure of plants and animals; presents to the eye myriads of beings, of whose existence we had before formed no idea; opens to the curious an exhaustless source of information and pleasure; and furnishes the philosopher with an unlimited field of investigation. It leads, to use the words of an ingenious writer, to the discovery of a thousand wonders in the works of his hand, who created ourselves, as well as the objects of our admiration; it improves the faculties, exalts the comprehension, and multiplies the inlets to happiness; is a new source of praise to him, to whom all we pay is nothing of what we owe; and while it pleases the imagination with the unbounded treasures it offers to the view, it tends to make the whole life one continued act of admiration. For there is no object so inconsiderable, that it has not something to invite the curious eye to examine it; nor is there any, which, when properly examined, will not amply repay the trouble of investigation.

It is not difficult to fix the period when the microscope first began to be generally known, and was used for the purpose of examining minute objects; for though we are ignorant of the name of the first inventor, we are acquainted with the names of those who first engaged the public attention, by exhibiting some of its wonderful effects. *Zacharias Jansen* and his son had made microscopes before the year 1619, for in that year the ingenious *Cornelius Drebell* brought one, which was made by them, with him into England, and shewed it to *William Borrell* and others. It is possible this instrument of *Drebell*'s was not strictly what is now meant by a microscope, but was rather a kind of microscopic telescope, something similar in principle to that lately described by Mr. *Aepinus*, in a letter to the Academy

of Sciences at Petersburg. It was formed of a copper tube six feet long and one inch in diameter, supported by three brass pillars in the shape of dolphins; these were fixed to a base of ebony, on which the objects to be viewed by the microscope were also placed. In contradiction to this, *Fontana*, in a work which he published in 1646, says, that he had made microscopes in the year 1618: this may be also very true, without derogating from the merit of the *Jansens*, for we have many instances in our own times of more than one person having executed the same contrivance nearly at the same time, without any communication from one to the other. In 1685, *Stelluti* published a description of the parts of a bee, which he had examined with a microscope.

If we consider the microscope as an instrument consisting of one lens only, it is not at all improbable, that it was known to the ancients much sooner than the last century; nay, even in a degree to the Greeks and Romans; for it is certain, that spectacles were in use long before the above-mentioned period. Now, as the glasses of these were made of different convexities, and consequently of different magnifying powers, it is natural to suppose, that smaller and more convex lenses were made, and applied to the examination of minute objects. In this sense, there is also some ground for thinking the ancients were not ignorant of the use of lenses, or at least what approached nearly to, and might in some instances be substituted for them.

OF THE OPTICAL EFFECTS OF MICROSCOPES.

It has been already observed, that the human eye is so constituted, that we cannot see an object distinctly when it is nearer the eye than six inches. To enable us to see objects nearer is the design of the

microscope, for by this means we are enabled to discern those objects which, from their minuteness, become imperceptible at a small distance. Hence a microscope is said to magnify the objects seen through it; but this expression is only true with respect to the apparent magnitude of the object.

To have right ideas on this subject, you must distinguish the apparent from the real magnitude of objects; the real magnitude of an object is the object of geometry, and remains invariable as long as the object continues in the same state; the apparent magnitude may be infinitely varied, while the real size remains unaltered. Thus the stars in the heavens appear to us exceeding small, although their real size is prodigious; this difference is occasioned by their immense distance. If we could approach them, we should find them increase in size as the distance diminishes; the apparent magnitude depending in a great degree on the angle under which it is seen, and this angle increases or diminishes, according as the object is nearer to or further from the eye.

Thus let P O Q, *plate* 8, *fig.* 4, be the object of our sight; this, if the eye be at A, will appear under the angle P A Q, called the visual angle, and which determines in a great measure the apparent size of an object. It is plain from hence, that the further the eye is from the object, the smaller is this angle; and that thus the largest bodies may be seen under an exceeding small angle, if they are at a sufficient distance.

If the eye be at B, the object will be seen under the angle P B Q, which is visibly larger than the angle P A Q. Let the eye be at C, the angle, P C Q, is larger than P B Q; and so on, the nearer the eye is to the object, the larger is the visual angle.

From hence it follows, that the apparent diameter of an object seen by the naked eye, may be

magnified in any proportion we please; for as the apparent diameter is increased in proportion as the distance from the eye is lessened, we have only to lessen the distance of the object from the eye, in order to increase the apparent diameter thereof.* Thus, suppose there is an object, AB, *plate* 8, *fig*. 5, which, to an eye at E, subtends or appears under the angle AEB, we may magnify the apparent diameter in what proportion we please, by bringing our eye nearer to it. If, for instance, we would magnify it in the proportion of FG to AB; that is, if we would see the object under an angle as large as FEG, or would make it appear the same length that an object as long as FG would appear, it may be done by coming nearer to the object. For the apparent diameter is as the distance inversely; therefore, if CD is as much less than CE, as FG is greater than AB; by bringing the eye nearer to the object in the proportion of CD to ED, the apparent diameter will be magnified in the proportion of FG to AB; so that the object AB, to the eye at D, will appear as long as an object, FG, would appear to the eye at E. In the same manner, we might shew, that the apparent diameter of an object, when seen by the naked eye, may be infinite. For since the apparent diameter is reciprocally as the distance of the eye, when the distance of the eye is nothing, or when the eye is close to the object at C, the apparent diameter will be the reciprocal of nothing, or infinite.

There is, however, one great inconvenience in thus magnifying an object, without the help of glasses, by placing the eye nearer to it. The inconvenience is, that we cannot see an object distinctly, unless the eye is about five or six inches from it; therefore, if we bring it nearer to our eye

* *Rutherforth's* System of Natural Philosophy, p. 330.

than five or six inches, however it may be magnified, it will be seen confusedly. Upon this account, the greatest apparent magnitude of an object that we are used to, is the apparent magnitude when the eye is about five or six inches from it: and we never place an object much within that distance; because, though it might be magnified by this means, yet the confusion would prevent our deriving any advantage from seeing it so large. The size of an object seems extraordinary, when viewed through a convex lens; not because it is impossible to make it appear of the same size to the naked eye, but because at the distance from the eye which would be necessary for this purpose, it would appear exceedingly confused; for which reason we never bring our eye so near to it, and consequently, as we have not been accustomed to see the object of this size, it appears an extraordinary one.

On account of the extreme minuteness of the atoms of light, it is clear, a single ray, or even a small number of rays, cannot make a sensible impression on the organ of sight, whose fibres are very gross, when compared to these atoms; it is necessary, therefore, that a great number should proceed from the surface of an object, to render it visible. But as the rays of light, which proceed from an object, are continually diverging, different methods have been contrived, as we have already shewn you, either of uniting them in a given point, or of separating them at pleasure.

Thus, by the help of convex lenses, we unite in the same sensible point a great number of rays, proceeding from one point of an object; and as each ray carries with it the image of the point from whence it proceeded, all the rays united must form an image of the object from whence they were emitted. This image is brighter, in proportion as there are more rays united; and more distinct, in

proportion as the order in which they proceeded, is better preserved in their union.

We perceive the presence and figure of objects by the impression each respective image makes on the retina; the mind, in consequence of these impressions, forms conclusions concerning the size, position, and motion of the object. It must however be observed, that these conclusions are often rectified or changed by the mind, in consequence of the effects of more habitual impressions. For example; there is a certain distance, at which, in the general business of life, we are accustomed to see objects: now, though the measure of the image of these objects changes considerably when they move from, or approach nearer to us, yet we do not perceive that their size is much altered: but beyond this distance, we find the objects appear to be diminished, or increased, in proportion as they are more or less distant from us.

For instance, if I place my eye successively at two, at four, and at six feet from the same person, the dimensions of the image on the retina will be nearly in the proportion of 1, of $\frac{1}{2}$, of $\frac{1}{3}$, and consequently they should appear to be diminished in the same proportion; but we do not perceive this diminution, because the mind has rectified the impression received on the retina. To prove this, we need only consider, that if we see a person at 120 feet distance, he will not appear so strikingly small, as if the same person should be viewed from the top of a tower, or other building, 120 feet high, a situation to which we had not been accustomed.

From hence, also, it is clear, that when we place a glass between the object and the eye, which from its figure changes the direction of the rays of light from the object, this object ought not to be judged as if it were placed at the ordinary reach of the sight, in which case we judge of its size more by habit than

by the dimensions of the images formed on the retina: but it must be estimated by the size of the image in the eye, or by the angle formed at the eye, by the two rays which come from the extremity of the object.

If the image of an object, formed after refraction, is greater or less than the angle formed at the eye, by the rays proceeding from the extremities of the object itself, the object will appear also proportionably enlarged or diminished; so that if the eye approaches to, or moves from, the last image, the object will appear to increase or diminish, though the eye should in reality remove from it in one case, or approach towards it in the other; because the image takes place of the object, and is considered instead of it.

The apparent distance of an object from the eye, is not measured by the real distance from the last image; for, as the apparent distance is estimated principally by the ideas we have of their size, it follows, that when we see objects, whose images are increased or diminished by refraction, we naturally judge them to be nearer or further from the eye, in proportion to the size thereof, when compared to that with which we are acquainted. The apparent distance of an object is considerably affected by the brightness, distinctness, and magnitude thereof. Now as these circumstances are, in a certain degree, altered by the refraction of the rays in their passing through different media, they will also, in some measure, affect the estimation of the apparent distance.

OF THE SINGLE MICROSCOPE.

The single microscope renders minute objects visible, by means of a small glass globule, or convex lens, of a short focus. Let E Y, *plate* 8, *fig.* 6, represent the eye; and O B, a small object situated

very near to it, consequently the angle of its apparent magnitude very large. Let the convex lens, RS, be interposed between the eye and the object, so that the distance between it and the object may be equal to the focal length, and the rays which diverge from the object, and pass through the lens, will afterwards proceed, and consequently enter the eye parallel: after which they will be converged, and form an inverted image on the retina, and the object will be clearly seen; though, if removed to the distance of six inches, its smallness would render it invisible.

When the lens is not held close to the eye, the object is somewhat more magnified; because the pencils, which pass at a distance from the center of the lens, are refracted inward towards the axis, and consequently seem to come from points more remote from the center of the object.

Plate 8, *fig.* 10, may, perhaps, give the reader a still clearer view, why a convex lens increases the angle of vision. Without a lens, as F G, the eye at A, would see the dart, BC, under the angle bAc; but the rays, BF and CG, from the extremities of the dart in passing through the lens, are refracted to the eye in the directions fA and Ga, which causes the dart to be seen under the much larger angle DAE, the same as the angle fAg. And therefore, the dart, B C, will appear so much magnified, as to extend in length from D to E.

The object, when thus seen distinctly, by means of the small lens, appears to be magnified nearly in the proportion which the focal distance of the glass bears to the distance of the objects, when viewed by the naked eye.

To explain this further, place the eye close to the glass, that as much of the object may be seen at one view as is possible; then remove the object backwards and forwards, till it appears perfectly dis-

tinct, and well defined; now remove the lens, and substitute in its place a thin plate, with a very small hole in it, and the object will appear as distinct, and as much magnified, as with the lens, though not quite so bright; and it appears as much more magnified in this case than it does when viewed with the naked eye, as the distance of the object from the hole, or lens, is less than the distance at which it may be seen distinctly with the naked eye.

From hence we see, that the whole effect of the lens or microscope is to render the object distinct, which it does by assisting the eye to increase the refraction of the rays in each pencil; and that the apparent magnitude is entirely owing to the object being seen so much nearer the eye than it could be viewed without it.

In other words, a single microscope removes the confusion that accompanies objects when seen very near the eye, while it leaves the visual angle the same. 1. It removes the confusion, for the object being placed in the focus of the lens, the rays emerging from thence are parallel, which you know is necessary to distinct vision. 2. The angle is the same, for whether the eye touches the glass, or is removed a little way from it, it appears under the same angle as it would to the eye placed where the glass is fixed.

Single microscopes magnify the diameter of the object, as we have already shewn, in the proportion of the focal distance (to the limits of distinct vision with the naked eye) to eight inches. For example, if the semidiameter of a lens, equally convex on both sides, be half an inch, which is also equal to its focal distance, we shall have as $\frac{1}{2}$ is to 8, so is 1 to 16; that is, the diameter of the object in the proportion of sixteen to one. As the distance of eight inches is always the same, it follows, that by how much the focal distance is smaller, there will

be a greater difference between it and the eight inches; and, consequently, the diameter of the object will be so much the more magnified, in proportion as the lenses are segments of smaller spheres.

As the closer the object is to the eye the larger it appears, it follows, that a double and equally convex lens is preferable to a plano-convex lens, because with equal convexities the focal length of the former is only half as long as the latter. Now, as the double convex consists of two segments of a sphere, the more an object is to be magnified, the greater must be the convexity, and therefore the smaller the sphere, till at last the utmost degree of magnifying power will require that these segments become hemispheres, and consequently the lens will be reduced to a perfect spherule, or very small sphere.

Very extraordinary magnifying powers may be obtained by means of small spherules, for the focus of parallel rays is only half the radius distant from the spherule; therefore, if the radius of the spherule be one-tenth of an inch, the eye will have distinct vision of an object by means thereof at the distance of a radius and an half, *i. e.* $\frac{3}{20}$ of an inch, which is but the fortieth part of six inches, so that the length of an object will be magnified 40 times, the surface 1600, and the bulk 64,000.

OF THE DOUBLE, OR COMPOUND MICROSCOPE.

In the compound microscope, the image is viewed instead of the object, which image is magnified by a single lens, as the object is in a single microscope. It consists of an object lens, L N, *plate* 8, *fig.* 8, and an eye-glass F G. The object, O B, is placed a little further from the lens than its principal focal distance, so that the pencils of

rays proceeding from the different points of the object through the lens, may converge to their respective foci, and form an inverted image of the object at PQ; which image is viewed by the eye through the eye-glass FG, which is so placed, that the image may be in its focus on one side, and the eye at the same distance on the other. The rays of each pencil will be parallel, after passing out of the glass, till they reach the eye at E, where they will begin to converge by the refractive powers of the humours; and after having crossed each other in the pupil, and passed through the crystalline and vitreous humours, they will be collected in points on the retina, and form a large inverted image thereon.

It will be easy, from what has been already explained, to understand the reason of the magnifying power of a compound microscope. The object is magnified upon two accounts; first, because if we viewed the image with the naked eye, it would appear as much larger than the object, as the image is really larger than it, or as the distance, f R, is greater than the distance f b; and secondly, because this picture is again magnified by the eye-glass, F G, upon the principle explained in the foregoing article on vision by single microscopes.

But it is to be noted, that the image formed in the focus of a lens, as is the case in the compound microscope, differs from the real object in a very essential particular; that is to say, the light being emitted from the object in every direction, renders it visible to an eye placed in any position; but the points of the image formed by a lens, emitting no more than a small conical body of rays, which arrives from the glass, can be visible only when the eye is situated within its confine. Thus the pencil, which emanates from O, in the object, and is converged by the lens to D, proceeds afterwards diverg-

ing towards H, and therefore never arrives at the lens F G, nor enters the eye at E. But the pencils, which proceed from the points o and b, will be received on the lens F G, and by it carried parallel to the eye; consequently, the correspondent points of the image, Q P, will be visible; and those which are situated farther out towards H and I, will not be seen. This quantity of the image Q P, or visible area, is called the field of view.

Hence it appears, that if the image be large, a very small part of it will be visible; because the pencils of rays will, for the most part, fall without the eye-glass F G. And it is likewise plain, that a remedy which would cause the pencils, which proceed from the extremes, O and B, of the object, to arrive at the eye, will render a greater part of it visible; or, in other words, enlarge the field of view. This is effected by the interposition of a broad lens, DE, of a proper curvature, at a small distance from the focal image. For, by that means, the pencil N D, which would otherwise have proceeded towards H, is refracted to the eye as delineated in the figure, and the mind conceives from thence the existence of a radiant point at Q, from which the rays last proceeded. In like manner, and by a parity of reason, the other extreme of the image is seen at P, and the intermediate points are also rendered visible. On these considerations it is, that compound microscopes are usually made to consist of an object-lens L N, by which the image is formed, enlarged, and inverted; an amplifying lens D E, by which the field of view is enlarged, and an eye-glass or lens, by means of which the eye is allowed to approach very near, and, consequently, to view the image under a very great angle of apparent magnitude. It is now customary to combine two or more lenses together at the eye-glass, in the manner of *Eustachio Divini* and M. *Joblot*; by

which means, the aberration of light from the figure is in some measure corrected, and the apparent field increased.

OF THE SOLAR MICROSCOPE.

In this instrument, the image of the object is thrown upon a screen in a darkened room. It may be considered under two distinct heads: 1st. The mirror and lens, which are intended to reflect the light of the sun upon the object; and, 2dly. That part which constitutes the microscope, or which produces the magnified image of the object, *plate* 8, *fig*. 9. Let N O represent the side of a darkened chamber; G H a small convex lens, fixed opposite to a perforation in the side N O; A B a plane mirror, or looking-glass, placed without the room to reflect the solar rays a, b, c, &c. on the lens C D, by which they are converged and concentrated on the objects fixed at E F.

2. The object being thus illuminated, the ray which proceeds from E, will be converged by the lens, G H, to a focus K, on the screen L M; and the ray which comes from F, will be converged to I, and the intermediate points will be delineated between I and K; thus forming a picture, which will be as much larger than the object, in proportion as the distance of the screen exceeds that of the image from the object.

GENERAL OBSERVATIONS.

From what has been said, it appears plainly, the advantages we gain by microscopes are derived, first, from their magnifying power, by which the eye is enabled to view more distinctly the parts of minute objects; secondly, that by their assistance, more

light is thrown into the pupil of the eye, than is done without them. The advantages procured by the magnifying power, would be exceedingly circumscribed, if they were not accompanied by the latter; for, if the same quantity of light is diffused over a much larger surface, its force is proportionably diminished; and therefore the object, though magnified, will be dark and obscure. Thus, suppose the diameter of the object to be enlarged ten times, and consequently the surface one hundred times, yet, if the focal distance of the glass was eight inches, provided this were possible, and its diameter only about the size of the pupil of the eye, the object would appear one hundred times more obscure when viewed through the glass, than when it was seen by the naked eye; and this even on the supposition, that the glass transmitted all the light which fell upon it, which no glass can do. But if the glass were only four inches focal distance, and its diameter remained as before, the inconvenience would be much diminished; because the glass could be placed twice as near the object as before, and would consequently receive four times as many rays as in the former case, and we should therefore see it much brighter than before. By going on thus, diminishing the focal distance of the glass, and keeping its diameter as large as possible, we shall perceive the object proportionably magnified, and yet remain bright and distinct. Though this is the case in theory, yet there is a limit in optical instruments, which is soon arrived at, but which cannot be passed. This arises from the following circumstances.*

1. The quantity of light is lost in passing through the glass.

* Encyclopedia Britannica, vol. viii. p. 5635.

2. The diminution in the diameter of the glass or lens itself, by which it receives only a small quantity of rays.

3. The extreme shortness of the focal distance of great magnifiers, whereby the free access of the light to the object we wish to view is impeded, and consequently the reflexion of the light from it is weakened.

4. The aberration of the rays, occasioned by their different refrangibility.

To make this more clear, let us suppose a lens made of such dull kind of glass, that it transmits only one half the light that falls upon it. It is evident, that supposing this lens to be of four inches focus, and to magnify the diameter of the object twice, and its own breadth equal to that of the pupil of the eye, the object will be four times magnified in surface, but only half as bright as if it was seen by the naked eye at the usual distance; for the light which falls upon the eye from the object at eight inches distance, and likewise the surface of the object in its natural size, being both represented by 1, the surface of the magnified object will be 4, and the light which makes it visible only 2; because, though the glass receives four times as much light as the naked eye does at the usual distance of distinct vision, yet one half is lost in passing through the glass. The inconvenience, in this respect, can only be removed so far as it is possible to increase the transparency of the glass, that it may transmit nearly all the rays which fall upon it; and how far this can be done, has not been yet ascertained.

The second obstacle to the perfection of microscopic glasses, is the small size of great magnifiers; by which means, notwithstanding their near approach to the object, they receive a smaller quantity of

light than might be expected. Thus, suppose a glass of only one-tenth of an inch focal distance; such a glass would increase the visible diameter eighty times, and the surface 6400 times. If the breadth of the glass could at the same time be preserved as great as the pupil of the eye, which we shall suppose one-tenth of an inch, the object would appear magnified 6400 times, and every part would be as bright as it appears to the naked eye. But if we suppose the lens to be only $\frac{1}{20}$th of an inch diameter, it will then only receive one-fourth of the light which would otherwise have fallen upon it; therefore, instead of communicating to the magnified object a quantity of light equal to 6400, it would communicate an illumination suited only to 1600, and the magnified object would appear four times as dim as it does to the naked eye. This inconvenience can, however, be in a great degree removed, by throwing a much larger quantity of light on the object.

This third obstacle arises from the shortness of the focal distance in large magnifiers; this inconvenience can, like the former, be remedied in some degree by artificial means of accumulating light; but still the eye is so strained, as it must be brought nearer the glass than it can well bear, which in some measure supersedes the use of very deep lenses, or such as are capable of magnifying beyond a certain degree.

The fourth obstacle arises from the different refrangibility of the rays of light, and which frequently causes such deviations from truth in the appearance of things, that many have imagined themselves to have made surprizing discoveries, and have communicated them as such to the world; when, in fact, they have been only optical deceptions, owing to the unequal refraction of the rays.

CONCLUSION.

After all that has been said on optics, &c. the question still occurs, What is light? how is it formed? and of what substance? These are questions that have been canvassed and disputed since the first origin of science and philosophy; and numberless are the conjectures which at different periods have arisen concerning them in the schools of learning.

Empedocles, one of the earliest philosophers of Greece, taught that light was an emanation of certain luminous atoms, subtile enough to pervade the invisible pores of air, water, and other diaphanous bodies. *Plato* seems to have been, in every material circumstance, of the same opinion; and further maintained, that colour is no more than an extremely rare and subtile flame, capable of penetrating the densest bodies. *Empedocles* accounted for vision in a two-fold way, that it was performed by the effluvia which proceed from the object, and by the emission of light from the eye, as from a lanthorn. The latter opinion is proved by a passage cited by *Aristotle*; it is a beautiful remains of antiquity. I shall give it you from *Sydenham*'s translation:

As when the trav'ller in dark winter's night,
Intent on journey, kindles up a light,
The moon-like splendor of an oil-fed flame,
He sets it in some lantern's horny frame;
Calm and serene there sits the tender form,
Screen'd from rough winds, and from the wintry storm.
In vain rude airs assault the gentle fire,
Their forces break, disperse, and they retire;
Fences secure, tho' thin, the fair inclose;
And her bright head she lifts amidst her foes.
Thro' the straight pores of the transparent horn,
She shoots her radiance, mild as early morn.

Forth fly the rays; their shining path extends,
Till lost in the wide air, their less'ning lustre ends.
So when the fire fresh lighted from on high,
Sits in the circling pupil of an eye;
O'er it, transparent veils of fabric fine
Spread the thin membrane, and defend the shrine;
The subtile flame inclosing like a mound,
Safe from the flood of humours flowing round.
Forth fly the rays, and their bright paths extend,
Till, in the wide air lost, their lustres end.*

Descartes maintained, that light, as it existed in the luminous body, is nothing but a power or faculty of exciting in us a very clear and vivid sensation; and that the invisible pores of lucid bodies are pervaded by a subtile and highly elastic matter, capable of being impelled by these bodies, and of producing on the organs of vision, when properly formed, the perception of light.

Sir *Isaac Newton* seems to have formed no direct opinion on the subject; from what he has said, we may conclude, he thought it consisted of solid particles of matter, when explaining more particularly the nature of light, he says, that it is refracted and reflected by an etherial medium, by the vibrations of which it communicates heat to bodies, and is put into fits of easy reflexion and transmission.

In the Peripatetic school, light was considered as a substance, neither purely spiritual nor purely corporeal, and was therefore defined a *materia media*; and indeed, when we contemplate with a philosophic eye the astonishing effects of light, we find

* Nor is this reasoning of the ancients to be altogether despised, for there are various arguments and experiments to prove that the seat of sense is not entirely passive in receiving images, but that it also directs a ray from itself to every object it perceives. The action and re-action between objects and the seat of sense is wholly reciprocal. *A. Wilson*, M. D. Medical Researches.

sufficient ground for accounting it of a nature widely different from lumpish, gross, inactive matter. That light however is material, cannot, as we have already shewn you, be disputed with any degree of probability. The materiality not only appears from its being propagated in time, but from its not bending into shadow. The solar rays are not only capable of being collected by a burning-glass, but when collected, exhibit marks of a power altogether irresistible. If a diamond, the hardest of terrene bodies, be placed in the focus of a burning-glass, the light immediately enters it, tears its parts asunder, divides and dissolves it. Here you perceive the lens acting upon the light, and the light upon the diamond. Since, therefore, light both acts and is acted upon, as matter, we must allow its properties to be material.

The unparallelled subtilety of light, and the impossibility of subjecting it to a chemical analysis, render every inquiry into its essence peculiarly arduous and difficult. Many and various are the phenomena which point out the most intimate and immediate connexion between fire and light. You all know, that those bodies which are heated most intensely, are most luminous, and that the light of the sun concentrated by convex glasses, produces a degree of heat almost irresistible. Here you perceive, that fire produces light, and light produces the most intense heat. If, therefore, the same causes produce the same effects, or, inverting the axiom, if the same effects proceed from the same causes, it must be inferred in the present instance, that light and fire are either one and the same substance, or at least in the immediate chain of cause and effect.

The connexion between fire and light is further evinced by the well-known effects of the latter on most bodies; innumerable experiments shew, that there is a certain degree of heat at which bodies be-

come luminous, and that all bodies which sustain that heat, without being converted into vapour, may universally be ignited. There are even some substances, which, though they evaporate at a degree of heat far below that at which they should begin to shine, may, by proper management, be ignited.

It now, I think, appears, that when *Plato* defined light "a rare and subtile flame," he came nearer the truth than later philosophers have in general imagined. Can you desire a more convincing proof of the solid judgment and penetration of that ancient sage, than that after the lapse of so many centuries, and the vast progress made in the science of nature, we are under the necessity of rejecting the theories of the moderns, to receive his long-exploded doctrine, as most consonant with facts and experiments. For, if to the arguments already used to prove the identity of fire and light, it be added, that light and heat diffuse themselves from a center outward, that they act in straight lines, and are subject to the same laws of reflexion, we can hardly hold our assent from the Platonic doctrine.

It may be further observed, that in general no light is excited until a decomposition takes place, and the fixed or latent fire begins to be separated from the bodies: light may be therefore considered as fire passing through certain strainers well-defined, and as existing in a more pure and simple state, and being less incumbered with heterogeneous gravitating matter than fire.

And if you survey the various operations of nature, with that attention and accuracy that are necessary in the prosecution of physical inquiries, I think I may venture to assert, that you will not meet with a single instance from which it can appear that light can be excited without the concurrence of the elementary principle of fire.

APPENDIX TO LECTURE XXII.

BY THE EDITOR.

CONTAINING A DESCRIPTION OF THE MODERN AND MOST IMPROVED ACHROMATIC AND REFLECTING TELESCOPES. *Plate* 9.

Our Author having in Lecture XXII. given the theories of the different telescopes in a concise manner, there appears to me only wanting a further description of them, according to the most approved mountings. Some knowledge of their construction and management in this respect I shall, therefore, endeavour to give to the reader, whereby he may be able to use any telescope in a ready manner, and be acquainted with the comparative advantages of the several kinds.

According to the principles upon which telescopes are now made, they are called *refractors* or *reflectors*. Of the former, the most perfect is that which contains a triple combined object-glass, and is, as our Author has before explained, called *achromatic*; of which I shall now describe the most simple constructed.

THE POCKET GALILEAN TELESCOPE.

This telescope, or pocket perspective glass, as it is sometimes called, takes its name from *Galileo*, from being constructed, after his invention, with only one concave eye-glass and one object-glass; the latter glass is now made on the achromatic principle, containing three glasses, *viz.* two convex and one concave interposed. *Fig.* 1 represents one of

the completest kind, mounted on its brass pillar and feet, which are so contrived, as to fold together and go within the inner tube of the telescope, and, when shut up, to form but one compact tube. This tube is of brass, and when the inner tube, &c. is shut in, is about five inches in length, and 1¾ inches in diameter. To use this instrument, the following particulars must be observed: draw the interior sliding tube, B, quite out of the external one, A; from the inner tube unscrew and draw out the pillar and feet, shewn at D; open the feet, screw off the pillar and, on the other side, screw it again to the piece; place the elevated piece at the top of the pillar, C, into the dovetail fixed to the tube at *a*; and then the telescope is mounted ready for use.

A steel screw is fixed into the bottom of the pillar, to fix the telescope by to a gate or trunk of a tree, &c. where there may not be room sufficient for the feet. In the circular eye-piece, E, are placed four concave eye-glasses of different concavities, to produce four different magnifying powers, and are used according to the brightness of the object. The glasses being fixed in an internal moveable wheel, any one may be easily brought to the center hole of the eye-piece by the application of a finger to the edge of the wheel. The number of the glass is shewn by an engraved figure at an hole made on one side: No. 1 produces the least power, and No. 4, the greatest. There are four circular marks upon the inner tube, B, marked with numbers corresponding to those of the eye-glasses. To one of these marks the tube may be previously set, agreeable to the number of the eye-glass, and a very little motion of the tube afterwards will be necessary to adjust the instrument to any eye. Different eyes will not be suited at the same mark precisely; the observer therefore should in this, as in all other telescopes, move the tube in or out slowly, while looking through it, till the object

appears most distinct. Different distances of the object to the same eye will also require a different position from the mark. A nice motion or adjustment may be had, by unscrewing the front part at *b*; but in this case it is supposed, that the tube is not sufficiently drawn out, the observer having first intentionally left this deficiency. A cell for containing a dark-coloured glass, for screening the eye when viewing the sun, is placed within the eye-piece, and is brought before the eye-glasses by pushing a pin projecting at the edge at *c*.

The magnifying powers by the different eye-glasses are 6, 12, 18, and 28 times; by the greatest power, the satellites of the planet Jupiter, and the ring of Saturn may be seen.

These pocket telescopes are more frequently made without stands, and with only one or two eye-glasses; in which manner they are sold at less expense.

The only inconvenience of *Galileo*'s telescope, when applied to terrestrial objects, is its confined field of view, the cause of which has been explained in Lecture XXII. It is of much advantage, as well as pleasure to the observer, to command an extent of view, when looking at an extensive landscape, &c. To afford which, pocket achromatic telescopes, with an improved system of four convex eye-glasses, have of late years been constructed, and generally adopted; they have undergone various degrees of improvements in the mounting, &c. and the following is of the best and most complete kind.

IMPROVED POCKET ACHROMATIC TELESCOPE.

The telescope, with its sliding tubes drawn out, and mounted on its portable brass stand, complete and ready for use, is represented at *fig.* 2. The sliding tubes are made of thin drawn brass, as com-

pleted by the late Mr. *Martin*, and, when shut up, contained in a mahogany, tortoiseshell, &c. tube. These tubes are not, like those of vellum and paper formerly made, subject to wear and irregularity; if well made, they slide easily and pleasantly: they pass through short thin brass springs, that are screwed at their ends, *a*, *a*, *a*, by which means they may at any time be taken out to be cleaned, &c. The four convex eye-glasses are contained in the smallest tube A, and are of such foci and diameters as to produce a large field of view. By screwing off this smallest tube at *a*, and sliding out two inner tubes containing at each end a glass, the glasses may be taken out, and thus easily cleaned, when necessary. To view the sun, a dark glass is sometimes fixed in a moveable brass screw cell, fixed at the eye-end of the smallest tube A.

The telescope, when shut, is nearly the length of the external wooden tube B. In using it, nothing more is necessary, than with the left hand on the tube B, and the right at the head of A, at one gentle pull to draw out the whole number of tubes to their utmost extent, as they are then stopped by the action of the springs against the shoulders at the ends of the tubes. Thus, an instantaneous view of any object suddenly presenting itself, is obtained. While you are looking through the telescope, the smallest tube, A, is the one to be pushed in slowly, till the most distinct appearance of the object is produced.

The portable stand is clamped to the largest of the sliding tubes by a screw at the rim *c*. The joint underneath admits of its motion either in a vertical or horizontal direction. When the stand is detached from the telescope, the pillar, *d*, is to be screwed on the under part of the piece, where it is in the figure represented as screwed to; the legs folded down upon it, and it then will go into a case

no longer than one for the telescope itself, with its tubes shut in. Thus together forming a very convenient telescope and stand for the pocket, when travelling, &c.

To persons unskilled in the management of a telescope for viewing any particular terrestrial object, or a planet or celestial body, a stand is a very useful and indispensable appendage.

These telescopes are made by us of various lengths and diameters, the annexed table will give the reader a more explicit idea of their dimensions, power, &c.

No.	Length when in use.	Length when shut.	Aperture of the achromatic object-glass.	Magnifying power in diameter, about	Weight.
1	14 Inches	5 Inches	1, 1 Inch	22 Times	6 Oz.
2	16 ditto	6 ditto	1, 2 ditto	25 ditto	8 ditto
3	22 ditto	7 ditto	1, 3 ditto	28 ditto	12 ditto
4	28 ditto	9 ditto	1, 6 ditto	35 ditto	16 ditto
5	40 ditto	10 ditto	2, 0 ditto	45 ditto	30 ditto
6	55 ditto	14 ditto	2, 5 ditto	60 ditto	50 ditto

Portable brass stands are most essential to the sizes No. 5 and 6. To which are sometimes adapted one or more extra eye-pieces, with two glasses of shorter foci to fit into the eye-end of the tube A, in room of the one contained therein, in order to increase the magnifying power for terrestrial objects, when the atmosphere is extraordinary bright and clear. A shorter eye-tube with two eye-glasses, called the *astronomical eye-piece*, is also occasionally made to screw to the second brass tube, in room of the tube containing all the day eye-glasses, for viewing the planets by night. It inverts the appearance, which in celestial objects is of no inconvenience, and gives a greater power and more light than a tube containing four eye-glasses only to shew objects erect. The tubes of the telescopes, No. 1 to 5, are very often made of copper plated with silver,

the rims, milled edges, and object-glass cell of silver; this gives them an elegant appearance, and as the tubes slide through cloth, they do not scratch, are more pleasant to the hands, and, in foreign hot climates, less liable to corrosion and a disagreeable smell.

The telescopes and stands are either packed into round pocket fish-skin, or leather cases, or in neat portable mahogany cases.

THE ACHROMATIC TELESCOPE WITH RACK-WORK MOTIONS.

It is of much importance in a good achromatic telescope, to have the number of tubes the least possible, for the eye-glasses will in that way have a perfect and steady motion, while adjusting to different eyes, and be also more consistent with the object-glass. In changing the direction of the telescope accurately from object to object by day, and also following the apparent motion of a celestial object by night, stands with rack-work motions are essentially necessary. The mode of adjustment to different eyes is also best by a contrivance of rack-work and pinion.

Fig. 3 is a representation of the construction of a telescope with all these advantages, and is presumed to be the most convenient and best of any hitherto made. The tube, A, is commonly made either about 2½ or 3½ feet in length, from which it is generally called the 2½ or 3½ feet refractor. This tube is made either of mahogany or brass, but the latter in hot climates is preferable. Within this tube moves an adjusting racked tube *g*, which is moved inwards or outwards by a pinion turned by the milled brass nut *f*. There is a long inner brass tube *e*, containing the four convex eye-glasses used by day, or for terrestrial objects; this tube is first drawn out

to a circular mark made thereon, and then, while you are looking through the telescope, a well-defined appearance of the object is obtained by turning the milled nut, *f*, with your hand to the right or left, as may be necessary. The telescope may have a vertical or horizontal motion given to it by the joint-work at D; and to produce this in an accurate degree, the rack B, for the vertical motion, must be connected to the tube by the projecting piece and pin, *a*, for that purpose. The rack-work for the horizontal motion is applied by pushing to the bottom of the pillar the lever *c*, and applying the handle, C, with *Hooke*'s universal brass joint; so that by the left hand taking hold of this handle C, and the right the ivory key at *b*, the changes of motion of the telescope, both vertically and horizontally, are produced very readily, and at the same time. By pulling back the lever *c*, it disengages the pinion from the rack, and a quick horizontal motion may thus occasionally be given.

A cell with a dark glass, for viewing the sun, is fitted to the screw-ring on the eye-end *d*. A spare tube with two eye-glasses, to increase the magnifying power when the atmosphere is very bright, is fitted to the end *d*, to be applied instead of one already placed there, and which may be readily pulled out by only first unscrewing the ring at *d*.

The *astronomical eye-piece*, *fig*. 5, for celestial objects, is to be screwed to the tube *e*, instead of the tube containing all the day eye-glasses, which is to be screwed off just beyond the circular mark usually made on the tube, as the distance nearly drawn it is to be drawn out for terrestrial objects. With this eye-piece, the tube, *c*, is first to be set to the mark, and the telescope adjusted to the eye by turning the milled nut *f*.

In the 2½ feet telescopes, the powers by the erecting eye-tubes, for terrestrial objects, are 45 and 55

times; by the astronomical eye-tube, 75 times. The whole instrument with its stand fold together, and pack into a portable mahogany case.

The powers of the $3\frac{1}{2}$ feet telescope, with the day eye-pieces, are 60 and 70 times, and with the astronomical tube, 110 times.

These telescopes for general use are the most to be recommended. The field of view, and brightness of the object shewn by them, are great and pleasant. Their powers, from the nature of the glass, are unavoidably limited, and the present impurities of white flint glass, of which the concave, that is placed between the two crown-glass convex ones, is made, is a farther diminution. It is by reflecting telescopes only that we can have large apertures and great powers.

OF IMPROVED REFLECTING TELESCOPES.

A reflecting telescope upon the Gregorian construction is preferable to any other, when it is to be used generally for terrestrial objects, and occasionally for celestial, by shewing the objects erect. The power of refractors, as I have just observed, are naturally limited; but those of reflectors are of considerable extent, and may with some advantage be extended to 5 or 6000 times, as verified by the very great assiduity and discoveries of Dr. *Herschel*. But it is not by the use of great powers that important discoveries have arisen; it is by the more considerable quantity of light from the largeness of their apertures, that distinct and useful observations of the heavens are made. Suppose two large reflectors of equal lengths and powers, but different apertures, the larger will render visible to the observer more stars, with equal definition and more brightness, than the smaller. The great improvement and advantage therefore of the best modern reflectors consist in

making a perfect one of the largest possible aperture, with the least length; and this we are now in the constant practice of performing. A reflecting telescope of seven feet in length, or seven feet focus of the great metallic speculum, and $6\frac{1}{4}$ inches diameter, made in the time of Sir *Isaac Newton*, we now make of only twenty-six inches in focus, and of the same diameter; which, with the assistance of an improved composition of the materials for the speculums, are capable of much greater magnifying powers.

The late ingenious Mr. *James Short*, who made the best reflecting telescopes in his time, for a four feet size telescope, or 36 inches focus of the great metal, had no more than 6,3 inches aperture.

OF THE IMPROVED GREGORIAN REFLECTING TELESCOPE, *fig.* 5.

Fig. 5 is a representation of a Gregorian reflecting telescope upon the improved method of mounting, with rack-work motions, &c. all of brass. It is made of various lengths and apertures, and for the purposes of being portable, or being moved about in a convenient manner, is the most to be recommended of any other kind.

When the tube or telescope, AB, is two feet in length, the diameter of the aperture, or great speculum, is generally four inches; when of three feet in length, the aperture is five inches. In using this telescope the following directions are to be observed.

The tube AB, when taken out of its packing-case, to be placed on its two bar rests, one of which is shewn at C D, and made fast thereto by the four nut screws, two of which are also shewn at C D. E is a sliding brass tube, to be connected to the object-end of the telescope by a pin at *a*, and the top of the base of the pillar by a dovetail piece at *b*. It

serves as a steadying tube, to prevent the vibration of the tube during a nice observation; *c* is a brass framed box, containing an endless screw, that acts upon teeth cut in the semicircular arch F. This box is acted upon by a spring underneath to keep it, when packed up, close to the arch. An handle G, with an *Hooke*'s universal joint, is fitted to the pinion, and when turned serves to produce an accurate and steady vertical motion of the telescope during an observation. There is also another spring box at H, with an endless screw acting into a ratchet wheel at the top of the pillar, which, by the assistance of the handle, I, and universal joint, will produce an accurate horizontal motion. In observing the apparent motion of the heavenly bodies, as well as terrestrial objects, these motions are of very considerable use. When a large motion at once of the telescope is wanted, the spring boxes may be pushed off from action in a ready manner, as they leave the tube quite free on its axis; this is a long axis fixed to the base H *b*, and goes down through the pillar, and is kept steady by a screw, and serves to keep the tube and rack-work apparatus quite steady while in motion.

The telescope is adjusted to different eyes, or distances of objects, while you are looking though it, by turning the long screw rod at the side, at K, to the right hand or left hand, as may be necessary. There are two small metallic speculums, *fig*. 6, and three to the larger telescopes, that are fitted by a dovetail slider, at *a*, to the inside of the object-end of the tube; and also two brass eye-pieces, *fig*. 7, containing the eye-glasses that are to be screwed in the front end of the telescope, all of which are for producing various magnifying powers, according to the state of the atmosphere or object to be observed. There is a dark glass fixed in a cell, screwed to the front of each of these eye-pieces, which, being in-

tended to screen the eyes from the sun, must be first screwed off, when that luminary is not to be viewed. L is a small glass telescope fixed and adjusted to the side of the telescope tube, called *a finder*. It contains two wires crossed at right angles to each other in the focus of the first eye-glass, and is useful for bringing any object readily into the field of view of the telescope, when great powers are used. For, by only first observing that the object is against the intersection of these wires in the finder, you will be certain of seeing it in the field of the telescope. The telescopes of about two and three feet in length, being of the lengths most generally made, I shall here insert the several magnifying powers of each.

Powers of the Two Feet, Four-Inch Aperture.

The longest eye-piece, *fig.* 7, used with the largest of the two small speculums, *fig.* 6	60 Times
The shortest eye-piece with the same speculum	100 ditto
The longest eye-piece with the smallest speculum	140 ditto
The shortest eye-piece with the same speculum	200 ditto

Powers of the Three Feet, Five-Inch Aperture.

The longest eye-piece with the largest of the three small speculums	60 Times
The shortest eye-piece with the same speculum	90 ditto
Longest eye-piece with the middle size speculum	120 ditto
Shortest eye-piece with the same speculum	180 ditto
Longest eye-piece with the smallest speculum	220 ditto
Shortest ditto with the same speculum	300 ditto

The reader must observe, that the light in this telescope, with the power of 60 times, exceeds the light of the former with the same power, in the proportion of the squares of the diameters of the apertures of the tubes, or as 25 to 16.

By an improved composition of the materials of the speculums, as well as a more perfect method of figuring them, we can make the tubes of much shorter lengths than formerly to the same apertures, or enlarge the apertures to the same lengths. Those of two feet we commonly reduce to nineteen inches, and those of three feet to thirty-one inches.

The only objection to be produced against the reflecting speculums, is their liability to tarnish in an atmosphere contiguous to the sea; but this, to an attentive and careful person, is of no weight. It is a practice, and should always be so with him, not to expose the metals in humid weather, and always carefully to close up the instrument when done with. From such precautions, no tarnish of any bad consequence can ever injure the mirrors. In the larger telescopes, for better security, the great speculum is contrived to be moveable from the tube, and shut up into a close-made brass box.

Reflecting telescopes, of greater lengths than three or four feet, we have found to be too weighty for such a rack-work for a vertical motion, as shewn at *c* F, *fig*. 5. We have constructed a four feet reflector, with a new contrivance for the vertical motion, consisting of a dovetail slider and piece placed near the object-end, B, of the tube, a long rod connected to the slider, going to the front at the under side of the tube; and two steady bars from the base, at *b*, to the dovetail slider. The rod being turned by an endless screw, acts upon the dovetail slider and steady bars, and produces a very accurate and steady motion from the horizon very near to the zenith, or to about 88°. The stand is framed of brass, with portable folding mahogany legs; and two of them being raised up occasionally, with wedges at their feet, will admit the telescope to be elevated to the zenith. For further particulars I must refer the reader to our printed descrip-

tion usually accompanying the instrument. Upon this principle, a telescope to the length of seven or eight feet may be mounted, with only some variation on the part of the stand.

Reflectors of still greater dimensions, as constructed by the celebrated Dr. *Herschel*, require a fabrication of wooden machinery quite different from any herein described, and also external detached premises upon the open ground. The reader will obtain an idea of his very curious and elaborate machinery, as applied to his forty feet reflector, by referring to the Philosophical Transactions for the year 1795.

The portable reflecting telescope has been used occasionally for exhibiting a perfect image of the sun during an eclipse or transit. It requires only the darkening of the room, and an hole cut in the shutter about the size of the aperture of the telescope, the telescope so placed as to admit the sun's rays directly through it, and a white paper or screen placed a few feet from it in a direction perpendicular to the tube. By turning the adjusting screw or rod on the side, a very well defined and beautiful representation of the sun will be exhibited on the paper, with all the spots, if any, in their true positions. The eye-pieces are to be screwed on without the dark glasses.

To either the achromatic or reflecting telescopes, apparatuses are occasionally applied to produce an equatoreal motion, to shew the altitudes, azimuths, right ascension, &c. &c. of the heavenly bodies at the time of observation, either by day or night. Also a *micrometer*, or an instrument to measure the angular distances of objects, while appearing in the field of view of the telescope, or the diameters of the sun, moon, &c. It is sometimes made of a fine slip of pearl, with divisions from 100 to 500th part of an inch cut upon it, and placed in the focus

of the first eye-glass; or of one of the eye-glasses bisected, and their motion shewing a separation of the image, indicated by a brass micrometer screw and scale placed on the outside.

A bisected object-glass has been applied to the object end of the telescope, to act in a similar manner to the bisected eye-glass above-mentioned; and also a bisected small speculum, with a complex construction of frame-work, has been applied to the object-end of reflecting telescopes; but neither of these methods, in my opinion, are to be preferred to the two others before mentioned, as being less simple.

A TRANSIT TELESCOPE.

This instrument consists of a telescope of any convenient length and aperture, fixed at right angles to an axis horizontally placed, which is so adjusted as to cause the telescope to move only and truly in the plane of the meridian of the plane, or other vertical circle, passing through the pole and zenith daily. Its principal use is to ascertain the rate or going of a watch or clock, and to give the right ascensions of the heavenly bodies observed, by observing the time of their passing over the wires fixed in the focus of the eye-glasses of the telescope. *Fig.* 7 is a representation of one of a portable and useful form; the telescope is about twenty inches in length, and the axis twelve inches. The dimensions of both these are occasonally varied according to the place whereon it is to be fixed, and the purposes of the observer.

END OF VOL. II.